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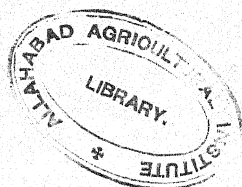
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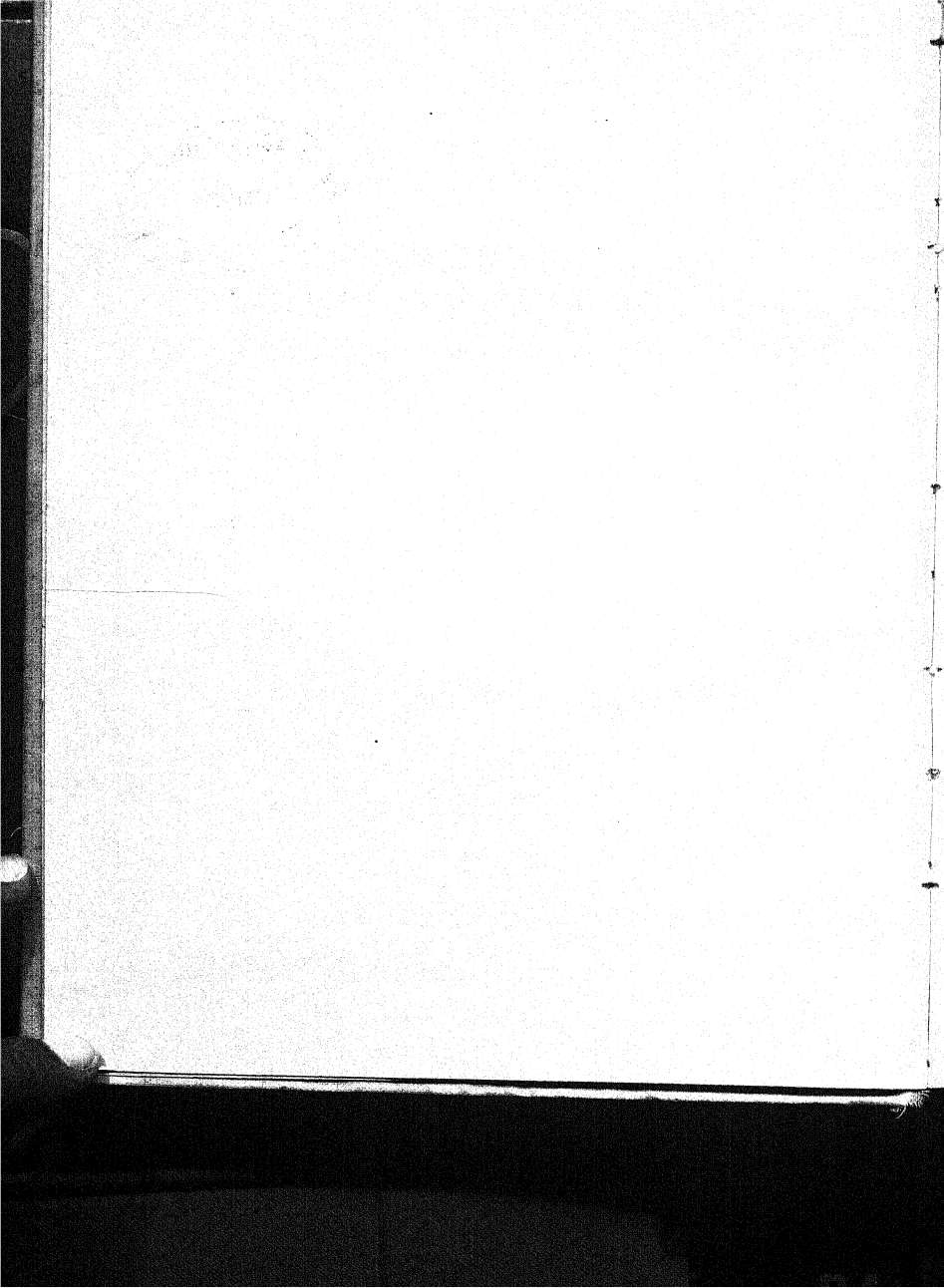
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# THE CALCULATION OF LINKAGE VALUES

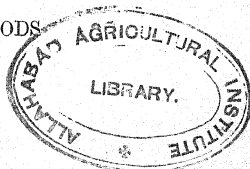
## A COMPARISON OF VARIOUS METHODS

BY

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(Received for publication on 17th December, 1928.)



### I. INTRODUCTION.

Undoubtedly the most direct method of finding out the Linkage-intensity is by making back-crosses between the heterozygous  $F_1$  individuals and the double-recessive and counting the number of offspring belonging to each phenotype; the proportions in which the various phenotypes are present will then directly express the gametic frequency. This method must always be used wherever possible, but its limitations are well known to geneticists and it is not always practicable. In most cases, therefore, we have to fall back upon the  $F_2$  population and try to get as accurate an idea of  $F_1$  gametic frequency as possible from the  $F_2$  distribution. It is therefore desirable to find out some mathematical method which can be generally used and which can be brought into a form well adapted to easy and quick manipulation without losing its efficiency.

Within the last few years there have been a number of publications on the methods of calculating Linkage-values and several formulæ have been developed to compute the gametic ratio from a given zygotic series of an  $F_2$  population. As a result of this, present day workers have to face the problem of deciding which method to choose rather than of finding out a new method. An endeavour has been made in the following pages to compare the various methods so far known and to discuss their merits and demerits and, if possible, to arrive at a method which would give satisfactory results in most cases. It has already been pointed out by Collins<sup>1</sup> and very recently by Fisher<sup>2</sup> that even among the best methods we may find some more suitable than others in special cases and that no one method should be regarded as the most accurate for all classes of deviation from a normal. Further, we must keep in mind while considering such problems that comparative-ly easy manipulation of one method over another of almost equal efficiency gives decided advantage to the former.

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<sup>1</sup> Collins, G. N. (1924). Measurement of linkage values. *Jour. Agric. Res.*, 27, 881-891.

<sup>2</sup> Fisher, R. A. and Bhai Balmakund (1928). The estimation of linkage from the offspring of selfed heterozygotes. *Jour. of Genetics*, 20, 79-92.

It has also been noticed by the writer that some of the older methods have a considerable disadvantage in that they deal with Coupling and Repulsion separately and give separate sets of formulæ and tables for the two phases of Linkage. An example of this is the method given by Alberts,<sup>1</sup> all of whose formulæ could be materially simplified by replacing 'r' and 's' by 'p' and '1-p' as is explained at a later point. Dr. Fisher has also suggested a very simple and efficient method for "Estimating Linkage from the Offspring of Selfed Heterozygotes" by calculating "the Product Ratio" and referring this value to a Table of calculated values for Coupling and Repulsion. This is not a very convenient process and further has the disadvantage of necessitating interpolation for intermediate values. The present writer suggests in this paper a very simple formula, which is applicable to both Coupling and Repulsion, for calculating the linkage intensity directly from the Product-Ratio.

Another feature of the older publications is that most authors deal with only simple dihybrid ratios, i.e., when the two linked-characters separately segregate in a 3:1 ratio. But with the modern development of Mendelism, present workers have often to deal with linkage relations in much more complex segregations. Hence it is highly desirable to find out some simple method by which workers can easily arrive at new formulæ applicable to their own special cases. In this paper an attempt has been made to this effect and a table is given (p. 14—15) which shows, for the more frequent phenotypic ratios, formulæ which can be used in estimating linkage-intensities.

As a result of these considerations, a number of new formulæ which are expected to be of material benefit in such calculations have been given in this paper. The formulæ suggested here are applicable to both Coupling and Repulsion and in such cases it is important to remember that 'p' always stands for the percentage of Cross-over in Repulsion, while in Coupling the percentage of Cross-over will be equivalent to '1-p.'

Before starting the actual comparison of the various methods, it is necessary to give an explanation of the symbols which are used in the following account. According to the usual notation, the four types of gametes formed by a heterozygote AaBb will be AB, Ab, aB and ab and they will be present in equal numbers when there is no linkage, otherwise the frequency of the extreme classes will be different from that of the middle ones. Whether linkage occurs or not, in all cases, we can represent the proportions of these four types of gametes by the following symbols and they will be true for all values of 'p':

Gametes:	AB	Ab	aB	ab	
	p	1-p	1-p	p	Ovules
	p'	1-p'	1-p'	p'	Pollen

<sup>1</sup> Alberts, H. W. (1926). A method of calculating linkage values. *Genetics*, 11, 235-248.

If we assume that  $p = p'$  i.e., the crossing-over is the same in male and female, then it can be shown by the well known checker board method that the effect of self-fertilization will be to produce an  $F_2$  generation in the following proportions :—

Phenotypes . . . . .	AB	Ab	aB	ab
Symbol used for observed frequency . . . . .	a	b	c	d
Theoretical proportions . . . . .	$2+p^2$	$1-p^2$	$1-p^2$	$p^2$

The sum of extreme phenotypic classes (a and d) is represented by 'E' and that of the middle classes (b and c) by 'M.' The total number of individuals (i.e. the population) is represented by 'n.'

The various methods, which are considered in the following account, are as follows :—

$$(1) \text{ Emerson, R. A. } p^2 = \frac{E-M}{n} \text{ or } \frac{2E}{n} - 1$$

$$(2) \text{ Alberts, H. W. } \frac{E}{M} = \text{Constant, 'p'}^2 \text{ from table}$$

$$\frac{16E}{n} = \text{Constant, 'k'}; \text{ 'p'}^2 \text{ from table}$$

$$(3) \text{ Yule, G. U. Co-efficient of Association}$$

$$\frac{ad-bc}{ad+bc} = Q; \quad p^2 = \frac{2 - \sqrt{4 - 2(Q^2 + Q)}}{2Q}$$

$$(4) \text{ Owen, F. V. Product Moment Co-efficient of Correlation}$$

$$r = \frac{ad-bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

$$p^2 = \frac{3r+1}{4}$$

$$(5) \text{ Haldane, J. B. S. } p^2 = T = \frac{3t_1t_2 + (2+t_1)t_4}{2+4t_1}$$

$$\text{where } t_1 = \frac{4a}{n} - 2; \quad t_2 = \frac{4d}{n}; \quad t_4 = \frac{1}{2}(t_1 + t_2)$$

$$(6) \text{ Fisher, R. A. Maximum Likelihood}$$

$$p^2 = \frac{(a-2b-2c-d) + \sqrt{(a-2b-2c-d)^2 + 8dn}}{2n}$$

$$(7) \text{ Fisher, R. A. Product Ratio :}$$

$$\frac{ad}{bc} = \text{Constant; 'p'} \text{ from table}$$

$$(8) \text{ Fisher, R. A. Weighted Mean}$$

$$p^2 = \frac{2(a-b-c)+10d}{4n}$$

(9) Fisher, R. A. Minimum  $\chi^2$ 

$$\chi^2 = \frac{4}{n} \left( \frac{a^2}{2+p^2} + \frac{b^2}{1-p^2} + \frac{c^2}{1-p^2} + \frac{d^2}{p^2} \right) - n$$

## II. CLASSIFICATION OF VARIOUS METHODS.

Adopting the classification, which is suggested by Dr. Fisher, of the various methods, we find the following groups:—

(a) *Additive methods*: where 'p' is determined from the values of E and M, i.e., the sum of the first and fourth, and of the second and third classes.

This includes all the methods suggested by Emerson<sup>1</sup> and Alberts,<sup>2</sup> in which the essential feature is that only the sum of the various classes is taken into consideration and hence all these methods give similar results.

(b) *Weighted mean method*: where 'p' is calculated from an alternative linear function of the frequencies; this method is given by Fisher.<sup>3</sup>

(c) *Product method*: 'p' is calculated from the relationship between the product of the first and fourth classes and the product of the second and third classes. It includes the Product Ratio suggested by Fisher<sup>3</sup> and also includes Yule's "Q," i.e., Co-efficient of Association.<sup>4</sup>

(d) *Method of maximum likelihood*: consists in maximising a quantity which can be written down by multiplying each observed number by the logarithm of the expectation. Thus—

$$a \log (2+p^2) + b \log (1-p^2) + c \log (1-p^2) + d \log p^2$$

is a maximum, if  $\frac{a}{2+p^2} + \frac{d}{p^2} = \frac{b+c}{1-p^2}$

leading to the formula 6 given on page 3.

This method was first applied by Haldane<sup>5</sup> and later but in a much simpler form given by Fisher<sup>6 and 7</sup>.

(e) *Method of minimum  $\chi^2$* , i.e., the measure of discrepancy ' $\chi^2$ ', the well known criterion of "goodness of fit," may be expressed as an explicit function of 'p' in the form

$$\chi^2 = \frac{4}{n} \left( \frac{a^2}{2+p^2} + \frac{b^2}{1-p^2} + \frac{c^2}{1-p^2} + \frac{d^2}{p^2} \right) - n$$

the condition that this should be a minimum leads to a quartic (i.e., biquadratic) equation for p<sup>2</sup>.

<sup>1</sup> Emerson, R. A. (1916). The calculation of linkage intensities. *Amer. Nat.*, 50: 411-420.

<sup>2</sup> I. c.

<sup>3</sup> Fisher and Balmakund (1928), *ib.*

<sup>4</sup> Yule, G. U. (1900). On the association of attributes in Statistics: 1. *Phil. Trans. Roy. Soc. A.* 194: 579-652.

<sup>5</sup> Haldane, J. B. S. (1919). The probable errors of calculated linkage values and the most accurate method of determining gametic from certain zygotic series. *Jour. Genetics*, 8, 291-297.

<sup>6</sup> Fisher, R. A. (1925). Theory of statistical estimation. *Proc. Camb. Phil. Soc.*, 22: 700-725.

<sup>7</sup> Fisher, R. A. (1922). On the mathematical foundations of theoretical statistics. *Phil. Trans. A. CCXXII*, 309-368.

(f) *Product moment co-efficient of correlation method.* This gives quite different results from other "Product methods" and hence may be considered as a separate group by itself. Dr. Fisher has not considered this method in his discussion. Its great advantage is its relation with  $\chi^2$ .

### III. COMPARISON OF METHODS.

#### (a) *Additive methods.*

Emerson's method, which belongs to this group, has often been recommended for calculating the linkage-intensities. The points in favour of this method are :—

- (1) Its extreme simplicity, which is characteristic of all additive methods.
- (2) Its general applicability, by the use of formulæ given by Collins,<sup>1</sup> for those zygotic distributions which are more frequently met with.

The first point loses its strength, when the question of efficiency comes up. Its inefficiency has been shown by Dr. Fisher,<sup>2</sup> who regards this method as the least efficient. He has calculated the efficiency percentage of the solutions obtained by this and several other methods for various Recombination values expressed in percentage; their relative efficiency is illustrated in Dr. Fisher's paper by means of a graph which is reproduced in this paper (Fig. 1). From the graph, it is evident that the efficiency of Additive methods (a) is nearly 100 per cent. in cases of close Coupling and nearly 0 per cent. in close Repulsion.

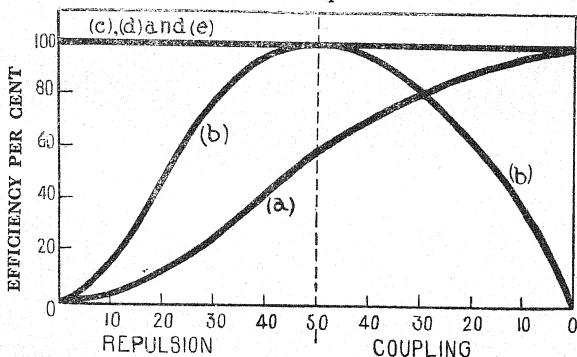


FIG. 1. RECOMBINATION PERCENTAGE

(After Fisher)

<sup>1</sup>l. c.

<sup>2</sup>Fisher and Balmakund (1928), *ib.*

Emerson<sup>1</sup> has compared the solutions arrived at by his method with those derived from Yule's Co-efficient of Association 'Q' by taking a few examples from some well known cases of Linkage. In this way he found that in most cases, when the observed frequencies do not deviate much from the theoretical, his method gives practically as good results as Yule's 'Q' and in no case is the value of  $\chi^2$  significant. In cases where the observed frequencies deviate widely from the theoretical, both the methods will give inaccurate solutions. In such cases the question is simply one of the degree of inaccuracy. These results, however, may be interpreted differently in the light of Dr. Fisher's recent investigations. One of the examples given by Emerson is one of close Coupling and in such cases we expect that the solutions obtained by the additive method will be quite reliable, as has been realized by Emerson. The example taken by Emerson for Repulsion phase is not one of close repulsion but gives a recombination value of about 30 per cent. Hence neither of these examples clearly shows the inefficiency of the method.

If, however, we take a case of close repulsion as given on page 33, it becomes evident how inaccurate a value this method gives in such cases. Unfortunately Emerson in his paper does not consider a case of close repulsion.

This inaccuracy of the additive method is not its only limitation. We find that, in cases where the observed frequencies deviate widely from the theoretical, this method gives very unreliable values as has been shown in Tables I—III.

As regards the general applicability of the additive method, we shall see in the following pages that a general method has been given by the application of which the value of 'p' can be directly calculated from any 'constant' expressed in terms of the phenotypic classes a, b, c and d and for any zygotie distribution (p. 45).

Another method of the Additive group similar to that of Emerson's is Alberts'.<sup>2</sup> He gives several separate tables and formulæ for Coupling and Repulsion. In calculating Linkage-values by his methods, it is necessary to refer to those tables. We can, however, arrive at the same results by using the following simple formulæ which give the value of 'p<sup>2</sup>' directly and which do not necessitate reference to a table. Thus—

$$p^2 = \frac{A-1}{A+1}, \text{ where } A = \frac{E}{M} \quad (1)$$

Similarly the value of 'p<sup>2</sup>' can be calculated from his constant 'k' by applying the formula :—

$$p^2 = \frac{k-8}{8}, \text{ where } k = \frac{16E}{n} \quad (2)$$

By using these formulæ all the tables given by Alberts can be discarded and the linkage-value can be calculated directly. The merits and demerits of Alberts' method are the same as those given for Emerson's method.

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<sup>1</sup> l. c.  
<sup>2</sup> l. c.

Hence the use of Additive methods as a general means of calculating linkage-values is not recommended, but they are not altogether to be discarded. Additive methods give much better results when one cross-over class or the double-recessive class is not recovered; this latter condition is the more likely to occur and in this case additive methods give the most accurate results, as is evident from Table III. In such cases, when one of the zygotic classes is missing, a modification of these methods as given below may be used with advantage.

When the double-recessive class is missing, 'p' may be calculated from:—

$$p^2 = \frac{2a-2M^*}{2a+M}$$

When one of the cross-over classes fails to appear

$$p^2 = \frac{E-2b}{n} \text{ or } \frac{E-2c}{n}$$

When the double-recessive class is missing, the value of 'p' may also be calculated from Alberts' constant 'k', or from the constant 'A' which is suggested at page 6 of this paper. Thus—

$$p^2 = \frac{2-2A}{1+2A}, \text{ where } A = \frac{E}{M} = \frac{a}{M}, \text{ in this case}$$

$$p^2 = \frac{k-8}{4}, \text{ where } k = \frac{16E}{n} = \frac{16a}{n}, \text{ in this case}$$

In cases where one of the cross-over classes is not recovered, the usual formulae (1) and (2) given on page 6 may be used, but the constant 'A' will naturally become—

$$A = \frac{E}{2b} \text{ or } \frac{E}{2c}$$

(b) *Weighted Mean method.*

This, according to Dr. Fisher, is slightly more efficient than the additive method, because the standard error of the estimate by this method is comparatively smaller. The method, therefore, makes use of a larger fraction of the information supplied by the data.

However, Tables I to III and examples given on pages 26—37 in this paper show that in some cases this method may give worse results than Additive methods and in no case does it show any definite superiority.

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\* *Jour. Agric. Res.*, 27 : p. 886.

(c) *Method of Maximum Likelihood.*

The advantages of this method are well appreciated and especially its relationship with the measure of discrepancy  $\chi^2$ . Dr. Fisher<sup>1</sup> has proved that this method will in all cases supply a solution of which the random sampling variance is as small as possible. The expression for the random sampling variance of the solutions of this method is applicable to some other methods as well and according to him the group of solutions which have the minimum random sampling variance may be termed "efficient statistics."

This and the next two groups of methods, which are considered in the following pages, have been classed under "efficient statistics" by Dr. Fisher and they are said to possess the following characteristics:—

- (1) All of them give solutions of which the random sampling variance is as small as possible and hence they may be said to convey the whole of the available relevant information supplied by the sample: their efficiency will always remain 100 per cent.
- (2) They agree so closely among themselves that no practical difference is to be expected between the conclusions drawn by using different methods of this class.
- (3)  $\chi^2$  measures the discrepancy between observation and hypothesis only when "efficient statistics" are used.<sup>2</sup>

The above characteristics of these methods are evident from the example worked out by Fisher<sup>3</sup> and are illustrated in this paper by taking several cases both of Coupling and Repulsion (pages 26—37). All the methods belonging to the class "efficient statistics" always give more or less similar results and the value of  $\chi^2$  is practically the same for solutions arrived at by these methods.

From these facts, it is evident that all these methods will give quite satisfactory results and will remain efficient under all conditions of Coupling and Repulsion. Hence, in comparing these methods the main question which arises is the comparative simplicity of calculation and their adaptability to various deviations from normal Mendelian ratios; these deviations may be due to a percentage of certain gametes being ineffective or to the unequal viability of zygotic classes. Such a comparison has already been made by Collins<sup>4</sup> and Owen.<sup>5</sup> The latter author expressed the zygotic classes as percentages and his tables are reproduced here. It must be noted that by "a" gametes in the tables Owen signifies those gametes which carry small "a" and not "A", and by "a" zygotes the phenotypes aB and ab. This use of these symbols must not be confused with their significance for zygotic frequencies (page 3).

<sup>1</sup> Fisher (1925), *ib.*

<sup>2</sup> Fisher, R. A. (1924). The conditions under which  $\chi^2$  measures the discrepancy between observation and hypothesis. *Jour. Roy. Stat. Soc.*, 87: 442-449.

<sup>3</sup> Fisher and Balmaund (1928), *ib.*

<sup>4</sup> L. G.

<sup>5</sup> Owen, F. V. (1928). Calculating linkage intensities by product moment correlation, *Genetics*, 13: 80-97.

TABLE I.

*Comparison of methods of measuring linkage in  $F_2$ .*

(After Owen.)

No actual gametic linkage.

No.	Form of population	ZYGOTIC CLASSES in per cent.				OBSERVED VALUES OF "p" FROM:—					
		a	b	c	d	Addi- tive methods	Weight- ed Mean	Fisher's 'P'	Owen's 'r'	Yule's 'Q'	Pro- duct Ratio
1	Perfect	50.25	18.75	16.75	6.25	50.00	50.00	50.00	50.00	50.00	50.00
2	25% 'a' gametes not effective.	61.22	20.41	13.78	4.59	56.23	50.00	50.00	50.00	50.00	50.00
3	25% 'a' and 'b' gametes not effective.	66.64	14.99	14.99	3.37	63.27	51.72	52.58	50.00	50.00	50.00
4	25% 'a' and 'B' gametes not effective.	54.98	20.66	12.36	0.00	46.86	47.94	47.97	50.00	50.00	50.00
5	25% 'a' zygotes die	60.00	20.00	15.00	5.00	54.77	50.00	50.00	50.00	50.00	50.00
6	25% 'a' and 'b' zygotes die.	64.00	10.00	16.00	4.00	60.00	50.99	51.33	50.00	50.00	50.00
7	25% 'a' and 'B' zygotes die.	55.38	24.62	13.85	0.15	48.02	48.82	48.88	50.00	50.00	50.00
8	25% 'a' zygotes called 'A.'	60.04	20.31	14.06	4.60	55.61	50.00	50.00	50.00	50.00	50.00
9	Double-recessive class not recovered.	60.00	20.00	20.00	0.00	44.72	31.62	0.00	25.00	0.00	0.00

NOTE.—(1) The additive methods always deviate appreciably from the actual linkage value of 50 per cent.  
 (2) The Weighted Mean method and the method of Maximum Likelihood (Fisher's) give practically the same results when there is no linkage (as is the case here) because the efficiency per cent. of the former method is 100 under these conditions.  
 (3) Yule's 'Q' and the Product Ratio 'P' give the actual linkage value in all cases except when the double-recessive class is not recovered. Owen's 'r' gives similar results only in this case when there is no actual gametic linkage. When the double-recessive class is not recovered, it gives half the actual value.

TABLE II.

*Comparison of methods of measuring linkage in  $F_2$ .*

(After Owen.)

Coupling Phase—25% actual Linkage-value.

No.	Form of Population	ZYGOTIC CLASSES IN PER CENT.				OBSERVED VALUE OF "p" FROM:—					
		a	b	c	d	Addi- tive methods	Weight- ed Mean	Fisher's 'p'	Owen's 'r'	Yule's 'Q'	Pro- duct Ratio
1	Perfect . . . .	64.06	10.04	10.04	14.06	75.00	75.00	75.00	75.00	75.00	75.00
2	25% 'a' gamete not effective.	70.41	11.23	8.04	10.33	78.41	72.17	75.82	74.17	75.06	75.69
3	25% 'a' and 'b' gametes not effective.	76.40	8.08	8.08	7.44	82.27	69.80	78.10	73.33	76.40	76.40
4	25% 'a' and 'B' gametes not effective.	63.51	14.06	7.76	13.77	73.87	74.04	73.95	74.56	75.02	75.02
5	25% 'a' zygotes die	68.33	11.67	8.75	11.25	76.02	72.16	75.00	73.08	75.00	75.00
6	25% 'a' and 'b' zygotes die.	72.40	9.28	9.28	8.05	79.30	70.28	75.85	73.01	75.00	75.00
7	25% 'a' and 'B' zygotes die.	63.48	14.45	8.13	13.94	74.05	74.37	74.18	74.08	75.00	75.00
8	25% 'a' zygotes called 'A.'	66.80	14.45	8.20	10.55	73.95	69.60	71.90	71.41	72.60	72.60
9	One cross-over class not recovered.	71.04	12.28	0.00	15.78	86.85	83.23	86.12	87.75	100.00	100.00

NOTE.—(1) The additive methods always deviate appreciably as is noticed even in Table 1.

(2) The Weighted Mean method and Fisher's Maximum Likelihood methods do not give similar values, the latter method giving somewhat better results.

(3) The results obtained from Owen's 'r' are in no way better than the previous method (i.e., Maximum Likelihood), in some cases it gives even worse results.

(4) Yule's Q and the Product Ratio again give similar results and much better than all other methods except when one cross-over class is not recovered.

TABLE III.

Comparison of methods of measuring linkage in  $F_2$ .

(After Owen.)

Repulsion Phase—25% actual Linkage-value.

No.	Form of Population	ZYGOTIC CLASSES IN PER CENT.				OBSERVED VALUES OF "p" FROM:—					
		a	b	c	d	Addi- tive methods	Weight- ed Mean	Fisher's 'p'	Owen's 'r'	Yule's 'Q'	Pro- duct Ratio
1	Perfect . . .	51.56	23.44	23.44	1.56	25.00	25.00	25.00	25.00	25.00	25.00
2	25% 'a' gametes not effective.	54.06	27.55	17.24	1.15	32.30	27.40	23.36	27.10	23.79	23.70
3	25% 'a' and 'b' gametes not effective.	57.82	20.66	20.66	0.86	41.66	32.25	23.48	28.74	22.60	22.60
4	25% 'a' and 'B' gametes not effective.	40.22	35.26	14.05	1.47	11.74	19.05	22.87	26.11	24.05	24.05
5	25% 'a' zygotes die	55.00	25.00	18.75	1.25	35.36	29.60	25.00	28.20	25.00	25.00
6	25% 'a' and 'b' zygotes die.	58.86	10.07	20.07	1.00	44.42	34.44	26.18	30.83	25.00	25.00
7	25% 'a' and 'B' zygotes die.	50.57	30.65	17.25	1.53	20.50	22.72	24.14	25.41	25.00	25.00
8	25% 'a' zygotes called 'A.'	57.42	23.83	17.58	1.17	41.46	33.10	26.40	30.65	26.00	26.00
9	Double-recessive class not recovered.	52.38	23.81	23.81	0.00	21.82	15.40	0.00	12.50	0.00	0.00

NOTE.—(1) The additive methods are very unreliable in this case. Their efficiency is lowest in repulsion phase.

(2) Weighted Mean method also gives quite bad results, but the method of Maximum Likelihood (Fisher's 'p') is as efficient here as in other cases (Tables 1 and 2) although it does show a certain amount of deviation from the actual value.

(3) Owen's 'r' is much less efficient in this case. Its results agree more to the Weighted Mean method than to any other method and hence not quite reliable in repulsion phase. When the double-recessive class is not recovered it gives half the actual value.

(4) Yule's Q and the Product Ratio methods give as satisfactory results as in previous cases.

These tables show clearly that the method of Maximum Likelihood is not to be recommended for general use. In spite of all the statistical efficiency possessed by this method we must not overlook the additional advantage enjoyed by the Product Ratio in being unaffected by differential viability. Dr. Fisher<sup>1</sup> himself says "The Product Ratio method enjoys the practical advantages of other efficient solutions, and is in addition unaffected by differential viability, if this is caused by one factor only. . . . It is also unaffected if both factors affect viability provided the percentage loss due to each factor is independent of the presence of the other." This point alone gives a decided superiority to the Product Ratio method, and it

<sup>1</sup> Fisher and Balmakund (1928), *ib.*

is recommended in this paper for general use. Further, it may also be noted that the method of Maximum Likelihood has not been so far brought into a form applicable to various phenotypic ratios and abnormalities in zygotic classes.

(d) *Method of Minimum  $\chi^2$ .*

Computation of the value of ' $p^2$ ' by this method is laborious as is evident from the expression given on page 4. In a recent publication Dr. Fisher<sup>1</sup> has pointed out that this method seems to possess no special theoretical interest and at the same time is laborious in computation. Hence, it need not be discussed in detail and it has been excluded even from the tables given in this paper. Under no condition can this method be recommended when others equally efficient and far simpler are available.

(e) *Product methods.*

This group includes two methods, one of which is recommended for general use. All the Tables and examples cited in this paper show definitely that the methods belonging to this group have certain decided advantages over all others and their general applicability has been made possible by means of several new formulæ which are given in this paper.

The co-efficient of association " $Q$ " has been a source of much controversy as a measure of correlation. Pearson and Heron<sup>2</sup> object vehemently to the application of this co-efficient when there is reasonable evidence of continuous variation. When, however, a character goes by 'units' there can be no objection to its use and, as pointed out by Owen<sup>3</sup>, the defects in the method as a measure of correlation really become an asset in estimating crossing-over percentages in certain instances. Its great advantage in such cases have been well appreciated by various authors from time to time (Collins<sup>4</sup>, Bridges<sup>5</sup>).

The great advantage of this method is due to the fact that " $Q$ " is based on the relationship that exists between the product of the two cross-over classes to the product of the two non-cross-over classes and hence it is unaffected by changes in zygotic frequencies. This is very clearly shown in Tables II and III where in Nos. 5 to 7 the value of ' $p^2$ ' agrees with that of a perfect population\* (No. 1) in spite of the fact that the Phenotypic ratios are very much disturbed due to the differential death-rate of zygotes.

<sup>1</sup> Fisher and Balmakund (1928), *ib.*

<sup>2</sup> Pearson, K., and Heron, D. (1913). On Theories of Association. *Biometrika*, 9: 158-315.

<sup>3</sup> Owen (1928), *ib.*

<sup>4</sup> Collins.

<sup>5</sup> Bridges, C. B. (1914). The chromosome hypothesis of linkage. *Amer. Nat.*, 48: 524-534.

\* By Perfect Population we understand a population which is not affected by any factor other than those under consideration. Thus, in the present case 'perfect population' would mean a theoretically correct population for simple dihybrid segregation or with 25% gametic linkage (Coupling or Repulsion) according to the Table under consideration.

"Q" is slightly affected by differential fertilization and by mistakes in classification, but much less so than is any other method under similar conditions (Tables II and III). However, the most usual cause of abnormal Mendelian ratios is a differential death-rate of zygotes and this has no effect on the value of "Q."

A glance at the Tables I to III shows clearly that "Q" also, as other constants, has its limitations. When any one class is missing, the results given by "Q" become very doubtful. In such cases the modifications suggested on pages 7 and 19 may be employed.

From the formulæ given on page 3 it is evident that Fisher's Product Ratio possesses exactly the same qualities as Yule's "Q" being dependent on the ratio of the product of the cross-over classes to that of the non-cross-over. It has got the further advantage of being simpler. The only drawback is that Dr. Fisher has given only one table (for a simple dihybrid ratio) by referring to which an approximate value of ' $p^2$ ' can be found out. For the general applicability of this method it is necessary to bring it into a form well adapted to easy manipulation and applicable to various complex Mendelian ratios. Hence a table has been prepared showing the value of the Product Ratio (P) in terms of ' $p$ ' (percentage of cross-over) and *vice-versa* (i.e. the value of  $p^2$  in terms of Product-Ratio P) for the various Phenotypic ratios which are commonly met with:—

TABLE IV.  
*Calculation of the value of 'p<sup>2</sup>', from the constant 'P' (=  $\frac{ad}{bc}$ ) for various Phenotypic Ratios.*

No.	Phenotypic ratios	PHENOTYPIC CLASSES IN PER CENT.				Value of 'P', in terms of 'p',	Value of 'p <sup>2</sup> ' from 'P'
		a	b	c	d		
1	1 : 1 and 1 : 1 Back- cross.	$\frac{p}{2}$	$\frac{1-p}{2}$	$\frac{1-p}{2}$	$\frac{p}{2}$	$\frac{p^2}{1-2p+p^2}$	$\left(\frac{P-\sqrt{P}}{P-1}\right)^2$
2	3 : 1 and 3 : 1 Link- age in one sex.	$\frac{2+p}{4}$	$\frac{1-p}{4}$	$\frac{1-p}{4}$	$\frac{p}{4}$	$\frac{2p+p^2}{1-2p+p^2}$	$\left(\frac{(P+1)-\sqrt{3P+1}}{P-1}\right)^2$
3	3 : 1 and 3 : 1 Link- age in both sexes.*	$\frac{2+p^2}{4}$	$\frac{1-p^2}{4}$	$\frac{1-p^2}{4}$	$\frac{p^2}{4}$	$\frac{2p^2+p^4}{1-2p^2+p^4}$	$\frac{(P+1)-\sqrt{3P+1}}{(P-1)}$
4	9 : 7 and 3 : 1 com- plementary fac- tors for one cha- racter.	$\frac{6+3p^2}{16}$	$\frac{3-3p^2}{16}$	$\frac{6-3p^2}{16}$	$\frac{3p^2+1}{16}$	$\frac{3p^4+7p^2+2}{3p^4-9p^2+6}$	$\frac{(9P+7)-\sqrt{(3P+5)^2+192P}}{6(P-1)}$
5	9 : 7 and 9 : 7 com- plementary fac- tors for both cha- racters.	$\frac{18+9p^2}{64}$	$\frac{18-9p^2}{64}$	$\frac{18-9p^2}{64}$	$\frac{10+9p^2}{64}$	$\frac{9p^4+28p^2+20}{9p^4-36p^2+36}$	$\frac{2\{(9P+7)-2\sqrt{63P+1}\}}{9(P-1)}$

6	15:1 and 3:1 Duplicate factors for one character.	$\frac{11+p^2}{16}$	$\frac{4-p^2}{16}$	$\frac{1-p^2}{16}$	$\frac{p^2}{16}$	$\frac{11p^2+p^4}{4-5p^2+p^4}$	$\frac{(5P+11)-\sqrt{(3P+1)^2+60P}}{2(P-1)}$
7	15:1 and 15:1 Duplicate factors for both characters.	$\frac{56+p^2}{64}$	$\frac{4-p^2}{64}$	$\frac{4-p^2}{64}$	$\frac{p^2}{64}$	$\frac{56p^2+p^4}{16+p^4-8p^2}$	$\frac{4^{\frac{1}{2}}(1+7)-\sqrt{7(P+7)+7P}}{(P-1)}$
8	15:1 and 9:7 Dup- licate factors for one and comple- mentary for the other character.	$\frac{33+3p^2}{64}$	$\frac{3-3p^2}{64}$	$\frac{27-3p^2}{64}$	$\frac{3p^2+1}{64}$	$\frac{9p^4+102p^2+83}{8p^2-90p^2+81}$	$\frac{(15P+17)-4\sqrt{(3P+4)^2+15P}}{3(P-1)}$
9	63:1 and 3:1 Triplicate factors for one character.	$\frac{47p^2}{64}$	$\frac{16-p^2}{64}$	$\frac{1-p^2}{64}$	$\frac{p^2}{64}$	$\frac{47p^2+p^4}{16-17p^2+p^4}$	$\frac{(17^{\frac{1}{2}}+47)-\sqrt{(17P+47)^2-64(P^2+P)}}{2(P-1)}$
10	27:37 and 3:1 Supplementary or 3 complementary factors for one character.	$\frac{18+9p^2}{64}$	$\frac{9-9p^2}{64}$	$\frac{30-9p^2}{64}$	$\frac{7+9p^2}{64}$	$\frac{9p^4+25p^2+14}{9p^2-39p^2+30}$	$\frac{(39P+25)-\sqrt{(21P+11)^2+3072P}}{18(P-1)}$

\* In all other cases linkage is in both sexes.

NOTE.—The Pincotypic classes a, b, c and d do not stand for the frequencies of the Pincotypes AB, Ab, aB and ab (as given on page 4), but they represent the crossover and non-crossover classes of two linked characters, each of which may be dependent on one or more factors. This has been more clearly explained on pages 46 and 47.

Table IV also throws some light on a simple method by which the value of 'p<sup>2</sup>' can be found out for any Phenotypic ratio and from any constant. This point will be discussed in detail later.

From the table it is clear that for the various Phenotypic ratios the formulæ given in the last column are simple and should not require more than few minutes for their calculation. All these formulæ are applicable to both Coupling and Repulsion and P always stands for  $\frac{ad}{bc}$  (cf. Fisher's P. R. =  $\frac{bc}{ad}$  for Coupling, and  $\frac{ad}{bc}$  for Repulsion).

The formulæ for the calculation of 'p<sup>2</sup>' from Yule's Coefficient of Association 'Q' and from the Product Ratio 'P' have been compared in Table V as shown below.

TABLE V.  
Calculation of 'p', from various constants compared.  
(After Owen.)

No.	Phenotypic ratios	VALUES OF 'p', FROM			
		E (Emmerson)	r (Owen)	Q (Yule)	P (Product Ratio)
1	1 : 1 and 1 : 1 (Back-cross).	$\left(\frac{E}{n}\right)^2$	$\left(\frac{r+1}{2}\right)^2$	$\left(\frac{Q+1-\sqrt{1-Q^2}}{2Q}\right)^2$	$\left(\frac{P-\sqrt{P^2}}{(P-1)^2}\right)^2$
2	3 : 1 and 3 : 1 Linkage in one sex.	$\left(\frac{2E}{n}-1\right)^2$	$\left(\frac{3r+1}{4}\right)^2$	$\left(\frac{2-\sqrt{4-2(Q+Q^2)}}{2Q}\right)^2$	$\left(\frac{(P+1)-\sqrt{3P+1}}{(P-1)}\right)^2$
3	3 : 1 and 3 : 1 Linkage in both sexes.*	$\frac{2E}{n}-1$	$\frac{3r+1}{4}$	$\frac{2-\sqrt{4-2(Q+Q^2)}}{2Q}$	$\frac{(P+1)-\sqrt{3P+1}}{(P-1)}$
4	9 : 7 and 3 : 1	$\frac{16E-7n}{6n}$	$\frac{\sqrt{2}r+1}{4}$	$\frac{(Q+8)-\sqrt{(Q+8)^2-24(Q+Q^2)}}{6Q}$	$\frac{(9P+7)-\sqrt{(3P+5)^2+192P}}{6(P-1)}$
5	9 : 7 and 9 : 7	$\frac{32E-14n}{9n}$	$\frac{7r+1}{4}$	$\frac{(Q+8)-\sqrt{64-2(31Q^2+Q)}}{9Q}$	$\frac{2\{(9P+7)-2\sqrt{63P+1}\}}{9(P-1)}$
6	15 : 1 and 3 : 1	$\frac{8E}{n}-5.5$	$\frac{3\sqrt{5r+1}}{4}$	$\frac{(8-3Q)-\sqrt{(8-3Q)^2-8(Q^2+Q)}}{2Q}$	$\frac{(5P+11)-\sqrt{(3P+11)^2+60P}}{2(P-1)}$
7	15 : 1 and 15 : 1	$\frac{32E}{n}-28$	$\frac{15r+1}{4}$	$2\{(8-6Q)-\sqrt{(8-6Q)^2-2(Q^2+Q)}\}$	$\frac{4\{(P+7)-\sqrt{7(P+7)+7P}\}}{(P-1)}$
8	9 : 7 and 15 : 1	$\frac{32E-17n}{8n}$	$\frac{\sqrt{105r+1}}{4}$	$\frac{(16-Q)-2\sqrt{64-14(Q+Q^2)}}{3Q}$	$\frac{(15P+17)-4\sqrt{(3P+4)^2+15P}}{3(P-1)}$
9	63 : 1 and 3 : 1	$\frac{32E-28.5}{n}$	$\frac{3\sqrt{21r+1}}{4}$	$\frac{(32-15Q)-\sqrt{(32-15Q)^2-32(Q^2+Q)}}{2Q}$	$\frac{(17P+47)-\sqrt{(17P+47)^2-64(P^2+P)}}{2(P-1)}$
10	27 : 37 and 3 : 1	$\frac{64E-25n}{18n}$	$\frac{\sqrt{37r+1}}{4}$	$\frac{(7Q+32)-\sqrt{(7Q+32)^2-72(11Q^2+Q)}}{18Q}$	$\frac{(39P+25)-\sqrt{(21P+11)^2-3072P}}{18(P-1)}$

\* In all other cases linkage is in both sexes.

The formulæ given by Owen<sup>1</sup> for similar calculation from the Product Moment Correlation 'r' and those given by Collins<sup>2</sup> have also been included in the above table.

The formulæ for 'P' are undoubtedly simpler than those for 'Q', but for the other two constants they are still simpler. However, one would prefer to calculate the value of 'p<sup>2</sup>' from the Product Ratio 'P' owing to the laborious calculation necessary for evaluating 'r'. Of course, the formulæ suggested by Collins are the simplest but the inefficiency of the method on which they are based makes them only of theoretical interest.

It is evident that the working of 'P' has been very much simplified through Table IV which has made it applicable to various complex Mendelian ratios. At the same time this method possesses all the advantages of Yule's Coefficient of Association as is evident from Tables I to III where the results for Q and P are always the same.

The only limitation of this method is in cases where one of the zygotic classes has not appeared. Some authors regard this as the great drawback of this group of methods, which is most efficient under all other conditions.

It is important, however, to note that in such cases even when we obtain somewhat satisfactory results with certain methods, they can never be regarded as theoretically correct. This can be shown as follows:—

$$\text{Emerson: } p^2 = \frac{E-M}{n}$$

when the class 'd' is absent, the above formula becomes  $p^2 = \frac{a-M}{n}$  which is theoretically incorrect.

If we substitute the value of 'a' and 'M' in terms of p<sup>2</sup>, we find that—

$$\frac{a-M}{n} = \frac{2+p^2-2+2p^2}{2+p^2+1-p^2+p^2} = \frac{3p^2}{4-p^2}. \text{ Therefore the expression } \frac{a-M}{n} \text{ is not in this case equal to } p^2.$$

$$\text{Similarly } p^2 = \frac{3r+1}{4} \text{ only when } r = \frac{ad-bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

When one of the classes a, b, c, d is absent, the above identities do not hold good.

The non-recovery of one of the zygotic classes can be explained in only two ways —

- (1) Errors in random sampling.
- (2) Close linkage reducing the chance of occurrence of the double recessive class.

<sup>1</sup> Owen (1928), *ib.*  
<sup>2</sup> l.c.

In most cases, it will not be possible to find out which one of the two causes is responsible for it. The first of these is more frequently met with and even when the second condition occurs, the first may also be partly acting. When one of the zygotic classes is not recovered due to errors of sampling, the value of  $p^2$  gets very inaccurate if we consider, in our calculations, even the missing class. This is evident from Table III, p. 11. Hence in such cases we should better base our calculations on the remaining 3 classes. If, however, the non-recovery of the fourth class is due to close linkage, the frequency of the other three classes must also be similarly affected and our calculation of the Cross-over percentage from these three classes should in no way be far from correct. Naturally, in all cases where one of the zygotic classes has not been recovered, it would be better to calculate Cross-over percentage from the remaining three classes.

Hence all the methods must be modified to make them applicable to these abnormalities. On these very lines Collins<sup>1</sup> has suggested the modification of the Additive method and here we may consider the Product Ratio method.

Usually the Product Ratio  $P = \frac{ad}{bc}$ , but, when the class 'd' has not been recovered, the product "ad" will be equal to zero and will convey no information. The only alternative left is to evaluate ' $p^2$ ' from the remaining 3 classes, a, b and c. With only three classes, the Product Ratio will become  $\frac{a \times a}{b \times c}$  i.e.  $\frac{a^2}{bc}$ .

When  $P = \frac{a^2}{bc}$ ;  $p^2 = \frac{(P+2)-3\sqrt{P}}{(P-1)}$ , when only 2 factors are involved.

When one of the cross-over classes is missing, the usual formula given in Table IV could be applied, but the Product Ratio will have to be modified as in the previous case.

$$P = \frac{ad}{b \times b} \text{ or } \frac{ad}{c \times c} \text{ instead of } \frac{ad}{bc}$$

In this case the formula for ' $p^2$ ' has not to be changed because theoretically  $bc = b^2 = c^2 = (1-p^2)^2$ .

While dealing with other phenotypic ratios, b and c may not be equal and in that case the formula for evaluating  $p^2$  has to be modified accordingly by the method suggested on pages 54—55.

In conclusion we find that the Product Ratio "P" with the formulæ given in this paper forms a very convenient and efficient constant for evaluating the value of ' $p^2$ ' from a given data. This method is, hence, recommended for general use in preference to all other methods with which it has been compared. It can also be used with the modifications just described even when one of the zygotic classes has not been recovered. An illustration of this is given on page 24.

(f) *Product Moment Coefficient of Correlation.*

Owen<sup>1</sup> has recently recommended a method for calculating Linkage intensities by the Product Moment Coefficient of Correlation 'r', which may be written as

$$r^2 = \frac{(ad-bc)^2}{(a+b)(c+d)(a+c)(b+d)}; \quad (p^2 = \frac{3r+1}{4})$$

a formula given by Prof. Karl Pearson<sup>2</sup>, not as the correlation between two characters but as the correlation 'hk' between the means, each measured in terms of their standard deviations, of two variates of a fourfold Gaussian table. Prof. Pearson<sup>3</sup> in a later publication states that "It becomes a true value of the correlation, when the two classes differ by a unit quantity as in the units of theoretical Mendelism." Thus there can be no objection to the above formula, if a, b, c and d are definite abstract values, i.e., if they do not spread over an interval. The points in favour of the Coefficient of Correlation are

(1) its relationship with  $\chi^2$

$$\chi^2 = n r^2 = \frac{(ad-bc)^2 (a+b+c+d)}{(a+b)(c+d)(a+c)(b+d)}$$

(2) a simple relationship between the coefficient of correlation of the zygotic phenotypes and the crossing-over percentage of 2 genetic factors under consideration. This is clearly shown in Table V where the value of 'p<sup>2</sup>' for various Phenotypic ratios could be calculated by simple formulæ if the value of 'r' is known.

However, we must consider that the value of 'r' itself is not quickly calculated. No doubt, for a theoretically perfect population of a dihybrid distribution  $a+b = a+c$  and  $c+d = b+d$  and thus the original formula may be simplified to

$$r = \frac{ad-bc}{(a+b)(c+d)}$$

But in practice we seldom realize this condition and thus the calculation of the correct value of 'r' will take much more time and labour than the working out of 'p<sup>2</sup>' from the Product Ratio (P). Considering the data, showing linkage between the sugary factor in maize and a factor for white base leaf, from Carver<sup>4</sup>, we find :—

STARCHY		SUGARY		Total
Green	White	Green	White	
1997	906	904	32	= 3839

<sup>1</sup> Owen (1928), *ib.*

<sup>2</sup> Pearson, K. (1900). Mathematical contributions to the theory of Evolution, VII. On the correlation of characters not quantitatively measurable. *Phil. Trans. A.*, Vol. 195: page 12.

<sup>3</sup> Pearson and Heron (1913), *ib.*

<sup>4</sup> Carver, W. A. (1927). A genetic study of certain chlorophyll deficiencies in maize. *Genetics*, XII, 415-440.

Now,

$$\begin{aligned}
 r &= \frac{(1997 \times 32) - (906 \times 904)}{\sqrt{2903 \times 936 \times 2901 \times 938}} \\
 &= \frac{63904 - 819024}{\sqrt{7393897942704}} = \frac{-755120}{271972.28} \\
 &= -.277702 \\
 p^2 &= \frac{3r+1}{4} \\
 &= \frac{-.833106+1}{4} = \frac{.166894}{4} = .0417235 \\
 p &= .20426; 1-p = .79574
 \end{aligned}$$

$$\begin{aligned}
 \text{While } P &= \frac{1997 \times 32}{906 \times 904} = \frac{63904}{819024} = .078024 \\
 p^2 &= \frac{1-.078024 - \sqrt{1-.234072}}{-.921976} = \frac{-.032864}{-.921976} \\
 &= .035645 \\
 p &= .18880; 1-p = .81120
 \end{aligned}$$

It is clear, therefore, that working out of the value of 'r' is a somewhat lengthy arithmetical process since the products (a+b) (c+d) (a+c) (b+d) will usually result in a number of 10 to 15 digits. While the easier manipulation of the value (P) is coupled with the additional advantage of its being unaffected by differential viability of zygotes. These two facts are sufficient to give a decided advantage to the application of the Product Ratio method and establish its superiority over the Product Moment Coefficient of Correlation; this is also evident from the Tables given on pages 9 to 11.

In certain cases, where a number of factors are involved and where, from the observed data, we know that there has been no differential viability of the zygotic classes, it may be of some advantage to calculate the linkage value from 'r'. But, usually, we shall find that 'r' will be laborious to work out and less efficient than the Product Ratio 'P'. This is very clear from the various examples worked out on pages 26 to 37 where the laborious computation of the value of 'r' is evident. In those examples we further notice that the value of  $\chi^2$  for this method is always much higher than that for the Product Ratio and in no case does this method give a better solution. Considering the laborious computation of the value of 'r' and the higher value of  $\chi^2$  for the solutions obtained by this method, it cannot be recommended for general use.

At this point it will be interesting to consider an example cited by Owen<sup>1</sup> where one of the zygotic classes has not been recovered. He regards this example as illustrating the usefulness of the coefficient of correlation as a measure of linkage because other methods give very inaccurate results under such conditions. Actually, we find from tables given by Owen<sup>2</sup> himself that in cases, where the double-recessive class is not recovered, Emerson's method gives a more correct value than the Coefficient of Correlation 'r'. From the following account it will be clear that even in this example the Recombination value obtained by Owen's method is very unreliable.

In this example, the two linked characters are the seed-coat and cotyledon colour in soy-beans. Duplicate factors  $D_1$  and  $D_2$  are assumed to be equally capable of producing yellow cotyledon colour and the factor  $D_1$  is linked with  $G$ , the factor for green seed-coat colour. The recessive characters are green cotyledon colour and yellow seed-coat colour respectively. The observed  $F_2$  data are:—

YELLOW COTYLEDONS		GREEN COTYLEDONS	
Green seed-coat	Yellow seed-coat	Green seed-coat	Yellow seed-coat
236	85	16	0

Owen has calculated the cross-over percentage by Emerson's method and got a value of 32 per cent., while the calculation from coefficient of correlation 'r' gives a value of 18.04 per cent. He considers the latter to be more correct. Yule's Coefficient of Association 'Q' and of course all the Product methods fail to express a logical cross-over value in such cases. On the lines suggested in this paper, however, cross-over percentage can be calculated even by Product methods when one of the zygotic classes has not been recovered. But the question arises how far is Owen justified in evaluating the cross-over percentage from the above data as it is. It has been pointed out by Owen<sup>3</sup> as well as by Woodworth<sup>4</sup> that the colour of cotyledon is determined one generation previous to the seed-coat colour and hence it is essential to sow these seeds in the known ratio of 15 yellow cotyledons to 1 green cotyledon, if we wish to get a correct idea of the relationship of the cotyledon and seed-coat colour. In the above data the ratio of yellow and green cotyledons is as 20 : 1. As a result of this the whole relationship is disturbed and we are not able to get a correct idea of the linkage-intensity. Further, when the actual observed

<sup>1</sup> Owen (1928), *ib.*

<sup>2</sup> Owen (1928), *ib.*, p. 91, Table IV (Repulsion Phase).

<sup>3</sup> Owen, F. V. (1927). Inheritance studies in Soy-beans. I. Cotyledon color. *Genetics*, 12 : 441-448.

<sup>4</sup> Woodworth, C. M. (1921). Inheritance of cotyledon, seed-coat, hilum and pubescence colors in soy-beans. *Genetics*, 6 : 511.

frequency is compared with the theoretical frequency for 50 per cent. cross-over value (*i.e.* no linkage) as given below,

	YELLOW COTYLEDONS		GREEN COTYLEDONS	
	Green seed-coat	Yellow seed-coat	Green seed-coat	Yellow seed-coat
	1	2	3	4
Observed frequency (O) . . . . .	236	85	16	0
Calculated frequency for 50% Cross-over (C)	236.96	78.98	15.80	5.26
O—C . . . . .	.96	6.02	.20	5.26
(O—C) <sup>2</sup> . . . . .	.0039	.4590	.0025	5.2600
$\frac{(O-C)^2}{C}$			$\chi^2$	= 5.7254

we find only two classes to show an appreciable deviation; this deviation may not be due to linkage, because in the first place it is restricted to only 2 out of the four classes (in case of linkage, all the classes will be similarly affected and show appreciable deviation), and secondly the value of  $\chi^2$  (= 5.7254) is not so high as to exclude the chance of the deviation being due to errors of sampling; the odds being only 8:1.

If, however, we correct the observed frequency on the lines suggested by Woodworth<sup>1</sup> and then compare with the calculated frequency for 50 per cent. Cross-over value, we find that all the classes deviate appreciably and suggest a certain amount of linkage, as is shown below:—

Classes	1	2	3	4
Corrected frequency (O') . . . . .	232.28	83.66	21.06	0
Calculated frequency for 50% Cross-over (C)	236.96	78.98	15.80	5.26
O'—C . . . . .	4.68	4.68	5.26	5.26
(O'—C) <sup>2</sup> . . . . .	.0924	0.2772	1.7500	5.2600
$\frac{(O'-C)^2}{C}$			$\chi^2$	= 7.3796

This value of  $\chi^2$  gives odds of nearly 16:1 (from Elderton's table). This deviation could never be attributed merely to the errors of sampling.

Only after this correction we are justified in finding out the linkage relationship of two such characters, one of which is determined one generation earlier. Undoubtedly, in such cases the best plan will be to sow the splitting seeds in the known proportions, but in case it has not been done it is essential to correct the data as suggested by Woodworth and then find out the linkage intensity. On the basis of the above corrected frequencies the cross-over percentage has been calculated by three different methods, namely, Additive, Product Ratio, and Coefficient of Correlation (Owen's 'r').

<sup>1</sup> Woodworth (1921), *ib.*

The usual Product Ratio method cannot be used in cases where one of the zygotic classes has not been recovered, but in such cases the modified Product Ratio, already suggested, may be employed as shown below :—

$$\begin{aligned}\text{Product Ratio "P"} &= \frac{a^2}{bc} = \frac{232.28 \times 232.28}{84.66 \times 21.06} = \frac{13488.50}{440.47} \\ &= 30.62 \\ p^2 &= \frac{(5P+22)-3\sqrt{P^2+80P}}{2(P-1)} = \frac{175.10-(3 \times 58.2)}{59.24} \\ &= \frac{50}{59.24} = .008440 \\ p &= 9.18; 1-p = 90.82\end{aligned}$$

The Additive method gives .014065 as the value of  $p^2$  with a cross-over percentage of 11.86, while the coefficient of correlation method gives .001293 as the value of  $p^2$  with a cross-over percentage of 3.60. The calculated frequency for each of these methods has been compared with the observed frequencies (corrected) as shown below :—

	YELLOW COTYLEDONS		GREEN COTYLEDONS		TOTAL
	Green seed-coat 1	Yellow seed-coat 2	Green seed-coat 3	Yellow seed-coat 4	
Observed frequency	236	85	16	0	337
Corrected frequency "O"	232.28	83.66	21.06	0	337
(i) Owen's "r"— Calculated frequency } $C_1$ when $p^2 = .001293$	231.7147	84.2228	21.0353	0.0272	337
$O'-C_1$	—0.5653	+0.5628	—0.247	+0.272	0
$(O'-C_1)^2$	.0014	.0038	..	.0272	.0324
$C_1$					
(ii) Product Ratio "P"— Calculated frequency } $C_2$ when $p^2 = .008440$	231.8653	84.0722	20.8843	0.1778	337
$O'-C_2$	—0.4147	+0.4122	—0.1753	+0.1778	0
$(O'-C_2)^2$	.0007	.0020	.0014	0.1778	.1819
$C_2$					
(iii) Additive method— Calculated frequency } $C_3$ when $p^2 = .014065$	231.9837	83.9538	20.7663	0.2962	337
$O'-C_3$	—0.2963	+0.2038	—0.2937	+0.2962	0
$(O'-C_3)^2$	.0004	.0010	.0042	0.2962	.3018
$C_3$					

\* For the derivation of this formula, see page 55.

The result obtained by Owen's "r" is very different from the other two methods. It gives a cross-over percentage of about 4, while the Product Ratio gives about 9 and the Additive method gives nearly 11. In all cases the value of  $\chi^2$  is much below one. It is, of course, the least for the lowest recombination value, because the double-recessive class has not been realized and the lowest recombination value reduces the chance of occurrence of the missing class to a minimum. For a recombination value of 2 or less, the value of  $\chi^2$  will be still reduced, irrespective of the efficiency of the method, as is evident from the following table:—

Methods	Value of "p <sup>2</sup> "	Cross-over percentage	Value of $\chi^2$ for all the 4 classes
(1) Arbitrary value . . . . .	·040000	20·00	0·8760
(2) Additive . . . . .	·014065	11·86	0·3018
(3) Product Ratio . . . . .	·008440	9·18	0·1819
(4) Owen's "r" . . . . .	·001203	3·60	0·0324
(5) Arbitrary value . . . . .	·000400	2·00	0·0138

This table clearly shows that the value of  $\chi^2$  rises with the value of "p<sup>2</sup>", irrespective of the methods employed. Actually we find that it is the double-recessive class which is, more or less, determining the value of  $\chi^2$ . If, however, we neglect the double-recessive class, which has not been recovered in the original data, and consider only the other 3 classes, the situation gets quite different as shown below:—

Methods	Value of "p <sup>2</sup> "	Cross-over percentage	Value of $\chi^2$ for classes 1, 2, and 3 only
(1) Arbitrary value . . . . .	·040000	20·00	·0360
(2) Additive . . . . .	·014065	11·86	·0056
(3) Product Ratio . . . . .	·008440	9·18	·0011
(4) Owen's "r" . . . . .	·001203	3·60	·0052
(5) Arbitrary value . . . . .	·000400	2·00	·0055

In this case the value of  $\chi^2$  is the minimum for the Product Ratio and is higher for all other values of "p<sup>2</sup>". Hence this value of  $\chi^2$  is dependent on the

efficiency of the method and it is a minimum for a *certain value* of " $p^2$ " and rises when *this value* is increased or decreased. We are further justified in neglecting the double-recessive class in comparing  $\chi^2$  values as this class has not been taken into consideration in evaluating " $p^2$ " by the modified Product Ratio method, with which all other methods are being compared.

This question, however, can also be tackled in another way. Looking at the theoretical Table III (p. 11), we find that in cases where the double-recessive class is missing (due to errors of sampling), the value of " $p$ " obtained from Owen's ' $r$ ' is 12.50 per cent. (half the correct value) when the actual gametic linkage is 25 per cent. On the basis of the theoretical tables we may regard the correct recombination value to be about 7 per cent. (i.e. twice the value (3.6) obtained by Owen's ' $r$ '), which is actually obtained by the modified Product Ratio method. Further we know that Additive methods are more reliable than other methods when the double recessive class is not realized and in this case as well 11 per cent. cross-over value, obtained by Emerson's method, is nearer to 9 per cent. than to 3.6 per cent. Unless Owen can establish the fact that the absence of the double-recessive class in the above example is wholly due to close repulsion and not also caused by errors in random sampling, the cross-over value, obtained by his method, must be very inaccurate.

Considering all these facts we may conclude that the cross-over percentage of 9 as arrived at by the modified Product Ratio method is a better estimate of linkage than the very low value of 3.6 per cent. obtained from the Product Moment Correlation method. The above discussion is not meant to convey the impression that the modified Product Ratio ( $\frac{a^2}{bc}$ ) is as efficient as the usual Product Ratio ( $\frac{ad}{bc}$ ), but it is simply to show that under such conditions, when one of the zygotic class is not realized, the modified Product Ratio gives rather the best estimate of the linkage relationships.

This again establishes the superiority of the Product Ratio method which can be used with reliance even in such cases.

#### EXAMPLES.

So far all the methods have been compared only theoretically with the help of Tables and formulæ, but it is essential to compare the actual results obtained by applying all these methods of evaluating recombination percentage to a few well-known cases of Linkage and then to calculate the value of  $\chi^2$  for each solution. We must take a few examples from both phases of linkage, i.e. Coupling and Repulsion.

(a) *Coupling.*

The well-known example of Coupling in sweet-peas as quoted by Punnett<sup>1</sup> may be first considered. The characters concerned are shape of pollen and colour of flower and the observed frequencies are:—

PURPLE		RED		
Long	Round	Long	Round	
(a)	(b)	(c)	(d)	
4831	390	393	1338	=6952

Now, we may calculate the value of ' $p^2$ ' by applying all the methods under consideration and calculate the value of  $\chi^2$  for each of them separately.

## (i) Additive Methods :

$$\text{Emerson : } p^2 = \frac{E-M}{n} = \frac{6169-783}{6952} = \frac{5386}{6952} = .774741$$

$$p = .880194 ; 1-p = .119806$$

$$\text{Albert : } p^2 = \frac{A-1}{A+1} \text{ where } A = \frac{E}{M} = \frac{6169}{783} = 7.87867$$

$$= \frac{6.87867}{8.87867} = .774741$$

Both these methods give exactly the same results. Hence only one of them will be considered in later comparisons.

From this estimate, we may calculate the value of  $\chi^2$  as given below:—

	PURPLE		RED		TOTAL
	Long	Round	Long	Round	
Observed frequencies	4831	390	393	1338	6952
Expected frequencies ( $m$ )	4822.502	391.499	391.499	1346.500	6952
Difference ( $d$ )	8.498	-1.499	1.501	-8.500	0
$\frac{d^2}{m}$	.0150	.0057	.0058	.0537	.0802

$$\chi^2 = \sum \frac{d^2}{m} = .0802$$

## (ii) Weighted Mean Method :

$$p^2 = \frac{2(a-b-c)+10d}{4n} = \frac{2(4831-390-393)+13380}{27808} = \frac{21596}{27808}$$

$$= .776611.$$

$$p = .881256 ; 1-p = .118744$$

<sup>1</sup> Punnett, R. C. (1922) *Mendelism* : Macmillan & Co., Ltd., London.

The value of  $\chi^2$  will be as follows :—

	PURPLE		RED		TOTAL
	Long	Round	Long	Round	
Observed frequencies	4831	390	393	1338	6952
Expected frequencies ( $m$ )	4825.752	388.248	388.248	1349.752	6952
Difference ( $d$ )	5.248	1.752	4.752	11.752	0
$\frac{d^2}{m}$	.0057	.0079	.0582	.1023	.1741

$$\chi^2 = \sum \frac{d^2}{m} = .1741$$

(iii) Method of Maximum Likelihood :

$$\begin{aligned}
 p^2 &= \frac{(a-2b-2c-d) + \sqrt{(a-2b-2c-d)^2 + 8dn}}{2n} \\
 &= \frac{1927 + \sqrt{(1927)^2 + 8 \times 1338 \times 6952}}{13904} \\
 &= \frac{1927 + \sqrt{3713329 + 74414208}}{13904} = \frac{1927 + 8838.98}{13904} \\
 &= \frac{10765.98}{13904} = .774308(11)
 \end{aligned}$$

The value of  $\chi^2$  will be as follows :—

	PURPLE		RED		TOTAL
	Long	Round	Long	Round	
Observed frequencies	4831	390	393	1338	6952
Expected frequencies ( $m$ )	4821.747	392.252	392.252	1345.747	6952
Difference ( $d$ )	9.253	2.252	0.748	7.747	0
$\frac{d^2}{m}$	.0177	.0129	.0014	.0445	.0765

$$\chi^2 = \sum \frac{d^2}{m} = .0765$$

(iv) Product Method :

$$(a) \text{ Product Ratio : } p^2 = \frac{(P+1) - \sqrt{3P+1}}{(P-1)} \text{ where } P = \frac{ad}{bc}$$

$$P = \frac{4831 \times 1338}{393 \times 390} = \frac{6463878}{153270} = 42.1731$$

$$p^2 = \frac{43.1731 - \sqrt{127.5193}}{41.1731} = \frac{31.8807}{41.1731} = .774308(95)$$

$$p = .879948; 1-p = .120052$$

$$(b) \text{ Yule's } Q : p^2 = \frac{2 - \sqrt{4 - 2(Q+Q^2)}}{2Q} \text{ where } Q = \frac{ad-bc}{ad+bc}$$

$$Q = \frac{6463878 - 153270}{6463878 + 153270} = \frac{6310608}{6617148} = .953674$$

$$p^2 = \frac{2 - \sqrt{4 - 2(.953674 + .909496)}}{1.907348} = \frac{2 - \sqrt{.27366}}{1.907348} = \frac{1.476875}{1.907348} = .774308$$

The value of  $\chi^2$  will be the same as in the previous case, i.e., .0765.

This is a very instructive example in showing that "efficient statistical methods" will give practically the same result with fairly large samples. In the example cited by Fisher,<sup>1</sup> the total population is about 4,000 and the value of ' $p^2$ ' calculated by the Product Ratio method and by the Maximum Likelihood method differ only in the fourth decimal place, while in this case with a population of about 7,000 we find these two methods agreeing up to the sixth decimal place, while in other cases with smaller populations we may find them differing even in the third decimal place.

(v) Method of Coefficient of Correlation :

$$p^2 = \frac{3r+1}{4} \text{ where } r = \frac{ad-bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

$$r = \frac{6463878 - 153270}{\sqrt{5221 \times 1731 \times 5224 \times 1728}} = \frac{6310608}{\sqrt{81582623580672}}$$

$$= \frac{6310608}{9032309.98} = .698670$$

$$p^2 = \frac{3.096010}{4} = .774002$$

$$p = .879774; 1-p = .120226$$

<sup>1</sup> Fisher and Balmakund (1928), *ib.*

The value of  $\chi^2$  will be as follows :—

	PURPLE		RED		TOTAL
	Long	Round	Long	Round	
Observed frequencies	4831	390	393	1338	6952
Expected frequencies ( $m$ )	4821.216	392.784	392.784	1345.216	6952
Difference ( $d$ )	9.784	-2.784	.216	-7.216	0
$d^2$	.01985	.01974	.00012	.03865	.07836
$m$					

$$\chi^2 = \sum \frac{d^2}{m} = .07836$$

The data just worked out are interesting in several respects. The above example is from a case where the observed frequencies of the separate characters (i.e., flower colour and shape of pollen grains) agree quite closely with the theoretical frequencies as is evident from the following :—

	Purple flower	Red flower	Long pollen	Round pollen
Observed frequencies	5221	1732	5224	1728
Theoretical frequencies ( $m$ )	5214	1738	5214	1738
Difference ( $d$ )	7	7	10	10
$d^2$	.0094	.0282	.0376	.0576
$m$				

It is well known that all the methods will give nearly correct solutions when there is not a wide departure between the theoretical and observed frequencies of the linked characters and it is also evident from Tables I to III that with a theoretically "perfect population" all the methods give absolutely correct result. Hence in the example just cited, where the theoretical and observed frequencies do not differ much, we find that in all cases the value of  $\chi^2$  is very insignificant and always below 1 as shown in the following table :—

Methods	Value of $p^2$	Recombination percentage	$\chi^2$
(i) Additive methods	.774741	11.9806	.0803
(ii) Weighted Mean method	.776611	11.8744	.1741
(iii) Maximum Likelihood method	.774308(11)	12.0052	.0765
(iv) Product methods	.774308(95)	12.0052	.0765
(v) Coefficient of Correlation method	.774002	12.0226	.0783

↑ See footnote p. 38.

The comparative efficiency of these methods cannot be found by referring to Elderton's tables<sup>1</sup> which do not include values of  $\chi^2$  below 1.\* However, we can judge the comparative efficiency of these methods from the values of  $\chi^2$  given by each method. A remarkable feature of the above table is that the Weighted Mean method gives the highest value of  $\chi^2$ , while the additive methods give much lower values. Apparently this would seem to overthrow Dr. Fisher's conception that additive methods are the least efficient, but actually this has confirmed his observations as regards the efficiency of the various methods. The above data are from an example of close Coupling and in such cases Additive methods are nearly 100 per cent. efficient, while the Weighted Mean method is least efficient.† This is what we actually get in this case.

Emerson has used this very example of Coupling in sweet-peas for comparing the solutions obtained from his method with those from Yule's Coefficient of Association "Q," but the actual data are different. He has taken the data quoted by Harris from the studies of Bateson, Saunders and Punnett<sup>2</sup> and they are:—

EXAMPLE (2).

Purple		Red		
Long	Round	Long	Round	
493	25	25	138	=681

Here again we find that the Additive methods give quite satisfactory results and compare well with other efficient methods, while the Weighted Mean method gives the highest value of  $\chi^2$  as shown in the following table:—

Methods	Value of $p^2$	Recombination percentage	$\chi^2$
(i) Additive . . . . .	.8531	7.64	.4688
(ii) Weighted Mean . . . . .	.8320	8.80	1.4654
(iii) Maximum Likelihood . . . . .	.8508	7.7610	.4571
(iv) Product Ratio . . . . .	.8507	7.7647	.4568
(v) Coefficient of Correlation . . . . .	.8487	7.8720	.8607

<sup>1</sup> Elderton, W. P. (1901). Tables for testing goodness of Fit. *Biometrika*, 1: 155-163.

\* Fisher (1922, *ib.*) gives value of  $\chi^2$  below 1 at page 98, but in all these cases the probability is above .90 and hence the deviations are not significant enough to enable us to arrive at any definite conclusion.

<sup>2</sup> Bateson, W., Saunders, E. R., and Punnett, R. C. (1908). Experimental studies of the Physiology of Heredity. Report IV, Evolution Committee, Roy. Soc., page 11.

† See Curves (a) and (b) in Fig. 1, page 5.

It may also be noted here as well as in the previous case that the Product Moment Coefficient of Correlation method always gives a value of  $\chi^2$  somewhat higher than that given by the Product Ratio or Maximum Likelihood methods.

### EXAMPLE (3).

We may take another case of Coupling where the recombination percentage is somewhere about 50 and see the comparative efficiency of all these methods under these conditions. Bateson and de Winton's data for the linkage of two factors in *Primula* as quoted by Fisher<sup>1</sup> may serve for this:—

The observed frequencies are:—

a	b	c	d	
396	99	104	70	=669

The recombination percentage and the value of  $\chi^2$  have been calculated by all the methods and the results obtained may be summarised in the following table:—

Methods	Value of p <sup>2</sup>	Recombination percentage	$\chi^2$
(i) Additive . . . . .	303124	37.300	4434
(ii) Weighted Mean . . . . .	405829	36.296	3907
(iii) Maximum Likelihood . . . . .	401557	36.632	3646
(iv) Product Ratio . . . . .	401524	36.634	3641
(v) Coefficient of Correlation . . . . .	403180	36.5036	3674

In this case we see clearly that the weighted mean method gives smaller value of  $\chi^2$  as compared to the additive method and that the weighted mean method approximates more closely to the "efficient statistical" methods in its solutions. However, the additive method also gives a fairly correct solution. The explanation of this lies in the graph given on page 5, where we find that for such high Recombination values, additive methods have got an efficiency of about 70 per cent. and hence the solution obtained from them is not far from the correct values.

Here again we notice that the Product Moment Coefficient of Correlation gives a higher value of  $\chi^2$  than the Product Ratio.

<sup>1</sup> Fisher, R. A. (1925). Statistical Methods for Research Workers. Oliver & Boyd, Edinburgh.

(b) *Repulsion.*

## EXAMPLE (4).

The relationship between the flower colour and shape of pollen in sweet-pea affords us with a case of Repulsion as well and the data given by Punnett<sup>1</sup> may be worked out by all these methods. The observed frequencies in this case are :

Flower	PURPLE		RED		
	Long	Round	Long	Round	
Pollen :	a	b	c	d	
	226	95	97	1	=419

(i) Additive method :

$$p^2 = \frac{227-192}{419} = \frac{35}{419} = .083532$$

$$p = .289019 ; 1-p = .710981$$

The value of  $\chi^2$  for this estimate will be :—

	a	b	c	d	
Observed frequencies	226	95	97	1	
Theoretical frequencies ( <i>m</i> )	218.25	96.0000	96.0000	8.75	
Difference ( <i>d</i> )	7.75	1.0000	1.0000	7.75	
$\chi^2 = \sum \frac{d^2}{m}$	.2749	.0104	.0104	6.8600	=7.1557

(ii) Weighted Mean method :

$$p^2 = \frac{2(226-95-97)-10}{1676} = \frac{78}{1676} = .046539$$

$$p = .215730 ; 1-p = .784270$$

The value of  $\chi^2$  will be :—

	a	b	c	d	
Observed frequencies	226	95	97	1	
Theoretical frequencies ( <i>m</i> )	214.375	99.875	99.875	4.875	
Difference ( <i>d</i> )	11.625	4.875	2.875	3.875	
$\chi^2 = \sum \frac{d^2}{m}$	.6300	.2380	.0826	3.0800	=4.0306

<sup>1</sup> Punnett, (1922), *ib.*

(iii) Maximum Likelihood method :

$$p^2 = \frac{(226-190-194-1) + \sqrt{(226-190-194-1)^2 \times 8 \times 1 \times 419}}{838}$$

$$= \frac{(-159) + \sqrt{(-159)^2 \times 3352}}{838} = \frac{\sqrt{25281 \times 3352} - 159}{838}$$

$$= \frac{10-21288}{838} = .012187(2)$$

$$p = .110396; 1-p = .889604$$

The value of  $\chi^2$  will be as follows :—

	a	b	c	d	
Observed frequencies	226	95	97	1	
Theoretical frequencies (m)	210.7766	103.4734	103.4734	1.2766	
Difference (d)	15.2234	8.4734	6.4734	.2766	
$\chi^2 = \sum \frac{d^2}{m}$	1.0995	.6939	.4050	.0599	=2.2583

(iv) Product Ratio :

$$P = \frac{226 \times 1}{95 \times 97} = \frac{226}{9215} = .024525$$

$$p^2 = \frac{1.024525 - \sqrt{1.073575}}{.975475} = \frac{-.0116096}{-.975475} = .0119015$$

$$p = .109094; 1-p = .890906$$

The value of  $\chi^2$  will be :—

	a	b	c	d	
Observed frequencies	226	95	97	1	=419
Theoretical frequencies (m)	210.7467	103.5033	103.5033	1.2467	=419.000
Difference (d)	15.2533	8.5033	6.5033	0.2467	=0
$\chi^2 = \sum \frac{d^2}{m}$	1.1039	.6985	.4086	0.0488	=2.2598

(v) Coefficient of Correlation method :

$$r = \frac{226-9215}{\sqrt{321 \times 98 \times 323 \times 96}} = \frac{-8989}{\sqrt{975449664}} = \frac{-8989}{31232.189}$$

$$= -.287812$$

$$p^2 = \frac{1-.863436}{4} = \frac{.136564}{4} = .03414$$

$$p = .184772; 1-p = .815228$$

The value of  $\chi^2$  will be as follows :—

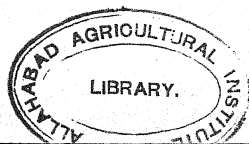
	a	b	c	d	
Observed frequencies	226	95	97	1	=419
Theoretical frequencies ( $m$ )	213.0763	101.1737	101.1737	3.5763	=419.000
Difference ( $d$ )	12.924	6.174	4.174	2.576	=0
$\chi^2 = \sum \frac{d^2}{m}$	.7838	.3767	.1722	1.8559	=3.1886

In order to compare the results obtained above, we may see the following table :—

Methods	Value of $p^2$	Recombination percentage	$\chi^2$
(i) Additive . . . . .	.083532	28.9019	7.1537
(ii) Weighted Mean . . . . .	.046539	21.5729	4.0306
(iii) Maximum Likelihood . . . . .	.012187	11.0396	12.2583
(iv) Product Ratio . . . . .	.011901	10.9094	12.2598
(v) Coefficient of Correlation . . . . .	.034141	18.4772	3.1886

The results obtained in this case agree more or less with those obtained by Fisher as given in the next table. We again find close agreement between the methods of Maximum Likelihood and Product Ratio, while the Coefficient of Correlation method departs significantly from these two methods.

Here, we strike at the very root of the efficiency of Additive methods and we get a very unreliable cross-over value by these methods. We can never harmonise 28.90 per cent. of cross-over value obtained by additive methods with 10.90 per cent. as obtained by Product Ratio method. The former value gives a gametic ratio of 2.46 : 1, while the latter gives 8.18 : 1. One of them must be very incorrect, and by calculating the value of  $\chi^2$ , we find that the additive method gives a value of 7.23 for  $\chi^2$ , while the product ratio gives a value of  $\chi^2$  of 2.25. Evidently the latter is the more reliable result.



## EXAMPLE (5).

Similar results have been arrived at by Fisher working with a data from Carver<sup>1</sup> showing linkage between the sugary factor in maize and a factor for white base leaf. The results are given in the following table:—

Methods	Value of $p^2$	Recombination percentage	Value of $\chi^2$
(i) Additive . . . . .	·057046	23·880	9·7170
(ii) Weighted Mean . . . . .	·045194	21·260	3·8600
(iii) Maximum Likelihood . . . . .	·035712	18·898	2·0154
(iv) Product Ratio . . . . .	·035645	18·880	2·0158
(v) * Coefficient of Correlation . . . . .	·041723	20·426	2·8010

The above values are strikingly similar to those obtained in Example 4.

## EXAMPLE (6).

In another case, where the recombination value approaches 50 per cent., we get somewhat different results. As an example of this, we may take the data given by Emerson.<sup>2</sup> Here the linked characters are form of flower (normal or cretin) and fertility of anthers as observed in sweet-peas by Bateson and Punnett<sup>3</sup>. The frequency of the various classes are:—

NORMAL		CRETIN		
Fertile	Sterile	Fertile	Sterile	
336	150	143	11	=640

The percentage of cross-over and the corresponding value of  $\chi^2$  have been calculated by all the methods and given in a tabular form as follows:—

Methods	Value of $p^2$	Recombination percentage	$\chi^2$
(i) Additive . . . . .	·084375	29·0474	·6490
(ii) Weighted Mean . . . . .	·076562	27·6700	·3565
(iii) Maximum Likelihood . . . . .	·071689	26·7748	·3016
(iv) Product Ratio . . . . .	·071677	26·7726	·3016
(v) Coefficient of Correlation . . . . .	·074734	27·3375	·3236

\* Not worked out by Fisher.

<sup>1</sup> l. c.

<sup>2</sup> l. c.

<sup>3</sup> Bateson, W., and Punnett, R. C. (1911). On the inter-relation of Genetic factors. *Proc. Roy. Soc. B.* 84, No. 568, 3-8.

The value of  $\chi^2$  is always below one, but its relative value is the same as in previous case, *i.e.*, the Additive method gives the highest value, then comes the Weighted Mean method and Coefficient of Correlation and the lowest value is given by the methods of Maximum Likelihood and the Product Ratio. Thus, in the Repulsion Phase, the additive methods can never give reliable results unless the population is "perfect", and they are absolutely unreliable in cases of close repulsion.

#### V. GENERAL CONSIDERATIONS.

In all the examples so far worked out, the value of  $\chi^2$  is in most cases very insignificant, although within each example it shows a certain relationship between the various methods for which its value is calculated. The relationship holds good for all the examples in spite of the great variation in the actual value of  $\chi^2$  from one example to another. Thus in example 1 (p. 27) the value of  $\chi^2$  varies from .07 to .170, while in example 2 (p. 31) from .45 to 1.46 and in example 3 (p. 32) from .36 to .44. But if we consider the relative value of  $\chi^2$ , as is suggested below, it is found to convey a certain relationship which is common to all these examples.

An idea of the relative value of  $\chi^2$  can be had by finding out the ratio of the actual value of  $\chi^2$  obtained for the solutions of each method to that of the value of  $\chi^2$  for the Product Ratio method. This relative value of  $\chi^2$  has been calculated for all the cases considered in the above account and is given in the following table:—

TABLE VI.

#### *Coupling-Phase.*

Methods	EXAMPLE No. 1 LINKAGE-VALUE NEARLY 5%		EXAMPLE No. 2 LINKAGE-VALUE NEARLY 10%		EXAMPLE No. 3 LINKAGE-VALUE NEARLY 40%	
	Actual value of $\chi^2$	Relative value of $\chi^2$	Actual value of $\chi^2$	Relative value of $\chi^2$	Actual value of $\chi^2$	Relative value of $\chi^2$
Additive . . .	.4688	1.026	.0802	1.048	.4434	1.216
Weighted Mean . .	1.4654	3.210	.1741	2.276	.3907	1.072
Maximum Likelihood .	.4571	1.000	.0765	1.000	.3646	1.000
Product Ratio . . .	.4568	1.000	.0765	1.000	.3644	1.000
Coefficient of Correlation	.8607	1.884	.0783	1.024	.3674	1.008

TABLE VI—*contd.**Repulsion-Phase.*

—	Example No. 4 Linkage-Value Nearly 10%		Example No. 5 Linkage-Value Nearly 20%		Example No. 6 Linkage-Value Nearly 30%	
Additive . . .	7-1557	3-168	9-7170	4-820	0-0490	2-152
Weighted Mean . .	4-0306	1-784	3-8600	1-916	0-3565	1-182
Maximum Likelihood .	2-2583	1-000	2-0154	1-000	0-3016	1-000
Product Ratio . . .	2-2598	1-000	2-0158	1-000	0-3016	1-000
Coefficient of Correlation	3-1886	1-411	2-8010	1-390	0-3236	1-073

From the above two tables it is clear that the relative value of  $\chi^2$  is always about the same for the two "efficient statistical" methods (iii and iv) and for all other methods it increases, sometimes considerably.

These tables also show that in Coupling Phase the Product methods give the lowest value of  $\chi^2$ , while in Repulsion the method of Maximum Likelihood gives the minimum value. Hence we may regard the latter method to be more efficient in Repulsion Phase and the former in Coupling, but actually the difference in the value of  $\chi^2$  for these two methods is so insignificant that either of them may be used under all conditions. The additional advantages possessed by the Product Ratio method make it valuable for general use.

Further it is interesting to calculate the value of  $\chi^2$ † for the original data, considering the two linked characters separately, and then compare it with the value of  $\chi^2$  for the linkage-values calculated by the Product Ratio method or by the method of maximum likelihood for all the examples. The following table shows this comparison :—

Data		Value of $\chi^2$ † for character A a+b : c+d	Value of $\chi^2$ † for character B a+c : b+d	Value of $\chi^2$ for the linkage value by Product Ratio method
Example No. 1 (Coupling)	. . . . .	.0376	.0768*	.0765
" " 2	" . . . . .	.4364*	.4364	.4568
" " 3	" . . . . .	.3700*	.0244	.3644
" " 4 (Repulsion)	" . . . . .	.9734	.5815	2-2594
" " 5	" . . . . .	.7840	.6575	2-0158
" " 6	" . . . . .	.3197*	.0652	.3015

\* The character showing widest deviation.

†  $\chi^2$  is not usually calculated when considering only one character but it has been done so, in this case, in order to show the close agreement between the two values (i.e., those marked \* and the corresponding values in the last column). The significance of this value of  $\chi^2$  cannot be found out by referring to Elderton's tables. It is simply of theoretical interest.

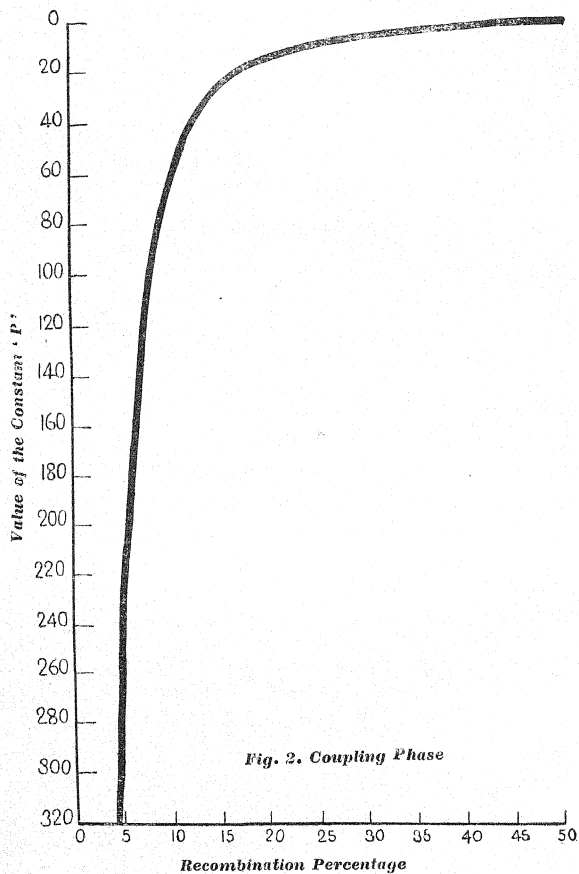
It is evident from the table that the value of  $\chi^2$  for the linkage-value obtained by efficient statistical methods is in most cases less than the value of  $\chi^2$  for the character showing the widest deviation from the theoretical frequency. Hence the value of  $\chi^2$  in the last column measures the discrepancy of the data itself and not the discrepancy of the solutions. As the value of  $\chi^2$  for the original data diminishes, the value of  $\chi^2$  for the efficient solutions also simultaneously decreases; this is evident from examples Nos. 1 and 2. Only in cases of close Repulsion (Examples Nos. 4 and 5) we find that the value of  $\chi^2$  is slightly significant. An explanation of this high value of  $\chi^2$ , in cases of close Repulsion, is to be found in the graphs given in Figs. 2 to 6.

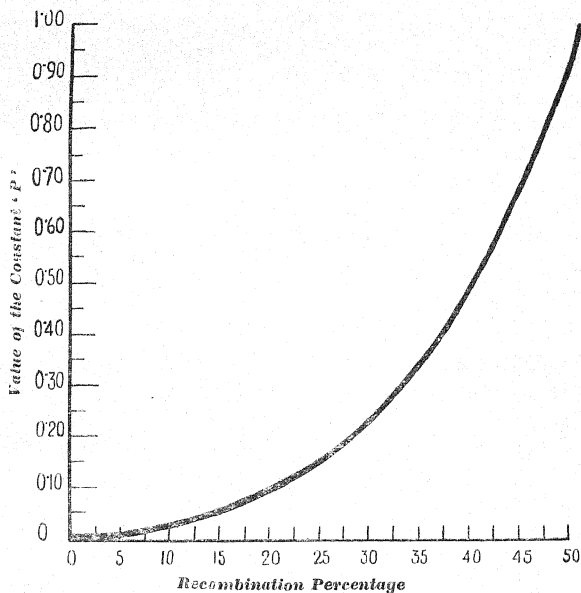
Figs. 2 and 3 show the relationship between the value of "P"—product ratio—and the percentage of cross-over for Coupling and Repulsion respectively. In the Coupling phase we find that with each rise of Recombination percentage the value of "P" falls down remarkably, especially in cases of close coupling. The difference is so great that it was not possible to show in the graph the value of "P" corresponding to very low Recombination values and hence they are given below to give an idea of this relationship:—

Recombination percentage	Value of "P"
1	7300
2	1812
3	792
4	438
5	275.5

The variation in the value of "P" is very remarkable in close coupling and its value is always more than 1. In Repulsion phase, the conditions are just the reverse, i.e., the value of "P" is always less than 1 and in close Repulsion the variation is very insignificant as is evident from Fig. 2. Hence, in cases of close Repulsion, the slightest change in the frequency of the zygotic classes will affect the Recombination value appreciably. In practice, due to errors of sampling, we seldom realize theoretically correct frequencies; this leads to error in Recombination value and consequently the value of  $\chi^2$  is also affected. Even with the most efficient methods we are sure to obtain fairly high values of  $\chi^2$ , when there is close repulsion.

The above facts also explain why even the less efficient methods give quite satisfactory results in cases of close coupling, while they absolutely fail in cases of close Repulsion. A still more clear idea of this relationship of Coupling and

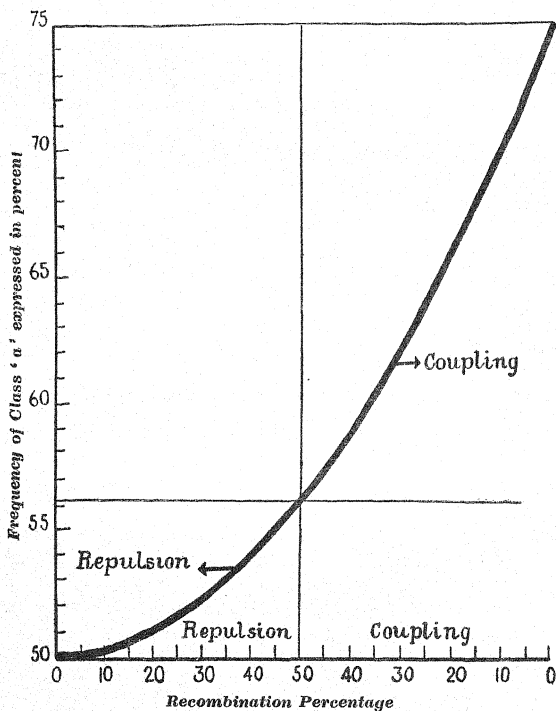


*Fig. 3. Repulsion Phase*

Repulsion is given by means of Fig. 4 where the relation between the frequency of zygotic classes and the Recombination values (for Coupling and Repulsion) has been shown in the same graph. The curve clearly shows that the zygotic classes vary much less in Repulsion than in Coupling.

Fig. 4. The Relationship of the frequency of zygotic class 'a' to the cross-over percentage.

The same curve will be true for other classes as well.



Albert's constant 'k', when plotted against the gametic frequency, gives, a curve (Fig. 6) very similar to the one obtained for the Product Ratio

Fig. 5

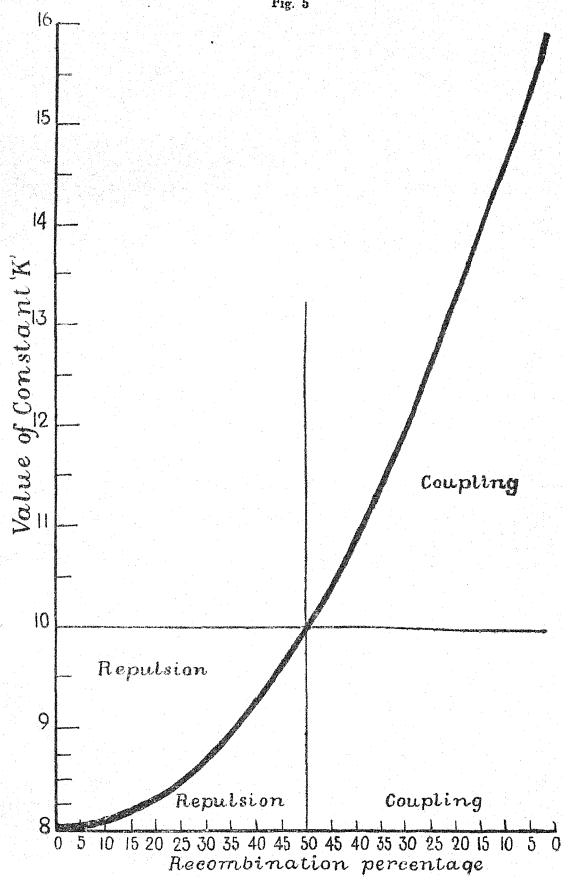
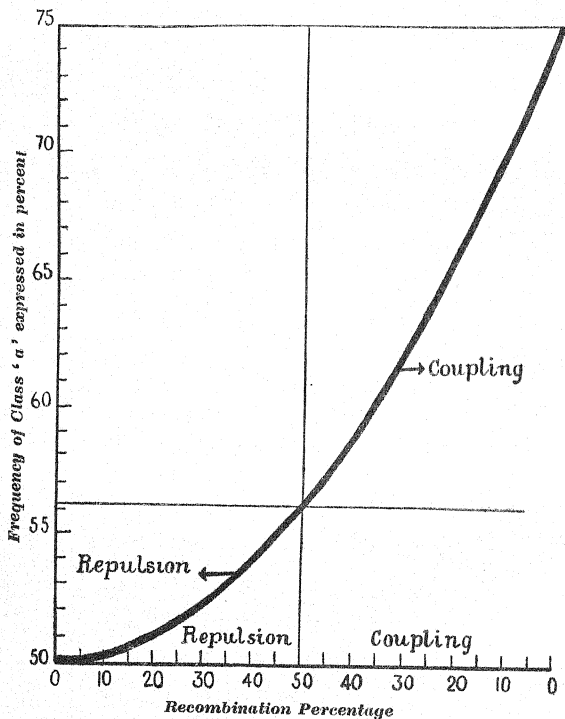


Fig. 4. The Relationship of the frequency of zygotic class 'a' to the cross-over percentage.

The same curve will be true for other classes as well.



Albert's constant 'k', when plotted against the gametic frequency, gives, a curve (Fig. 6) very similar to the one obtained for the Product Ratio

Fig. 5

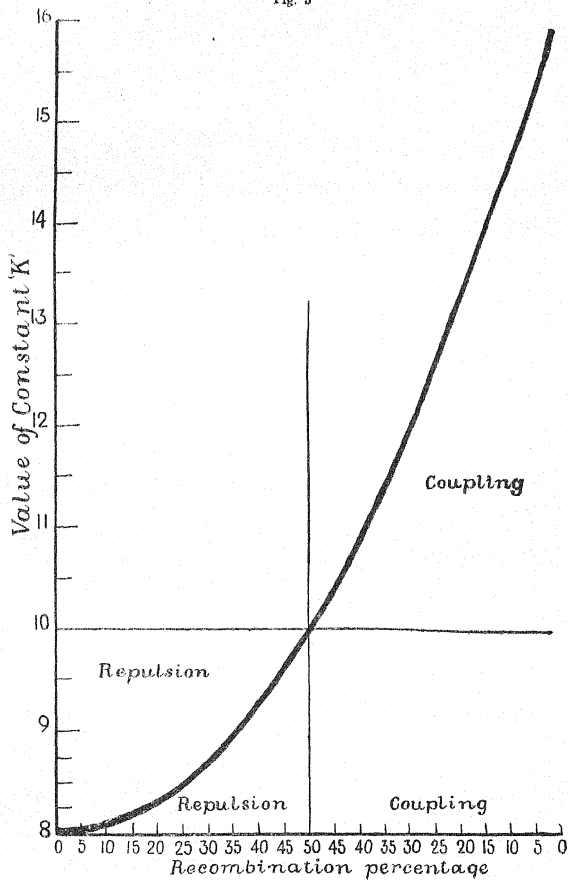
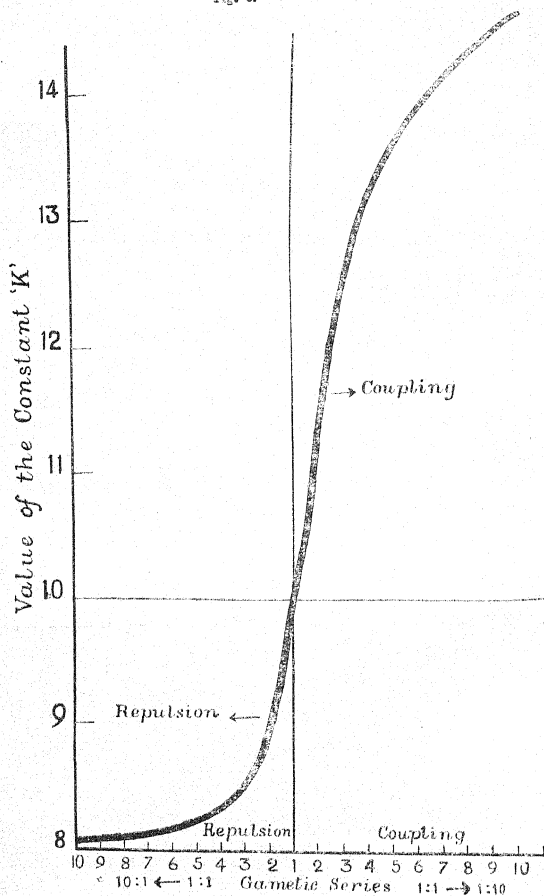


Fig. 6.



"P". In this case the variation is not so great and hence the two curves for Coupling and Repulsion could be shown in the same graph. Even in this case the variation of the constant 'k' is much more in Coupling than in Repulsion.

All these facts point to the practical difficulties in obtaining an accurate Recombination value in cases of close Repulsion; while with close Coupling even appreciable deviation in zygotic classes does not affect the Recombination value significantly. That is why Additive methods have been so often successfully used in cases of close Coupling.

The examples worked out in the previous pages have served as practical illustrations of the theories propounded by Dr. Fisher as regards the efficiency of the various methods of calculating linkage-values. These examples clearly show the limitations of the various methods and establish the superiority of the Product ratio method and that of the Maximum likelihood.

Out of these two methods, the former is recommended for general use because of its additional advantage in being unaffected by differential viability of the zygotic classes.

#### VI. A METHOD FOR FINDING OUT THE VALUE OF " $p^2$ " FROM ANY CONSTANT AND FOR ANY ZYGOTIC SERIES.

This is based on the relationship that exists between any gametic series and its corresponding zygotic series. The fundamental method of representing the phenotypic ratios in terms of gametic series is the one given by Bateson and Punnett<sup>1</sup> where two separate formulæ are given for Coupling and Repulsion. Thus—

<i>Gametic series.</i>				
Coupling .	AB	Ab	aB	ab
	$n-1$	1	1	$n-1$
Repulsion .	1	$n-1$	$n-1$	1
<i>Zygotic series.</i>				
	AB	Ab	aB	ab
Coupling .	$3n^2-(2n-1)$	$2n-1$	$2n-1$	$n^2-(2n-1)$
Repulsion .	$2n^2+1$	$n^2-1$	$n^2-1$	1

However, Emerson<sup>2</sup> has suggested a general formula for calculating a phenotypic zygotic series from a given gametic ratio. He represents the gametic ratio by  $r:s$  and then the gametic series will be  $r:s:s:r$  and the zygotic series for dihybrid segregation both for Coupling and Repulsion will be:—

$$3r^2 + 2(s^2 + 2rs) : s^2 + 2rs : s^2 + 2rs : r^2$$

<sup>1</sup> Bateson and Punnett (1911), *ib.*  
<sup>2</sup> *l. c.*

and the sum of the zygotic series will be  $(2r+2s)^2$ . The above series can be obtained for any segregation by writing out the Genotypes in terms of 'r' and 's' and then adding up the phenotypes separately. On this basis Woodworth<sup>1</sup> has derived several formulæ specially applicable to his particular problem, where one of the linked characters is determined by Duplicate factors.

From his tables<sup>2</sup> as well as from the formulæ, it is evident that the process is not a simple one. His formulæ could be simplified materially by substituting 'p' and '1-p' for r and s respectively. This has also been suggested by Collins<sup>3</sup> who has shown how Woodworth's formula (2) for two characters segregating in the ratios 15:1 and 3:1 which is given as

$$12r^2 + 11(s^2 + 2rs) : 3r^2 + 4(s^2 + 2rs) : s^2 + 2rs : r^2$$

becomes  $11 + p^2 : 4 - p^2 : 1 - p^2 : p^2$

if 'p' and '1-p' are used for the cross-over and non-cross over gametes instead of 'r' and 's'. So far there has been no suggestion for avoiding the complicated process followed by Woodworth in arriving at the above formula. A very simple method for representing the zygotic series in terms of gametic series is suggested in the following pages.

But before coming to this, we must clearly understand what relationship exists between the symbols a, b, c and d in dealing with linkage problems where numerous Mendelian factors are concerned and hence the number of theoretical phenotypes increases with the number of factors involved. In considering the linkage relationship of any two characters, we have to deal with only 4 phenotypes at a time, however complex may be the characters. In sweet-peas, we come across linkage between sterility of anthers and form of flowers; this may be written in terms of a, b, c and d as follows:—

	A	a
	Normal	Cretin
B	Normal Fertile	Fertile Cretin
Fertile	AB (a)	aB (b)
b	Normal sterile	Sterile cretin
Sterile	Ab (c)	ab (d)

As each of these characters are actually dependent on single factors, their distribution in the above form is quite easy to understand. Now, let us assume that

<sup>1</sup> Woodworth, C. M. (1923). Calculation of linkage intensities where duplicate factors are concerned. *Genetics*, 8: 106—115.

<sup>2</sup> *Genetics*, 8: pp. 108 and 112.

<sup>3</sup> *I.e.*

\*Normal Flowers are due to the interaction of 2 factors A and B giving a 9 : 7 ratio of Normal and Cretin flowers, and that the fertility of the anthers is caused by the presence of a single factor C. According to normal Mendelian conception, the various theoretical Phenotypes will be :—

27 ABC	Normal Fertile
9 ABc	„ Sterile
9 Abc	Cretin Fertile
9 aBC	„ „
3 abC	„ „
3 aBc	„ Sterile
3 Abc	„ „
1 abc	„ „

These phenotypes, when expressed in the  $2 \times 2$  fold table terminology, will become

ABC Normal Fertile (a)	AbC + aBC + abC Fertile Cretin (b)
ABc Normal Sterile (c)	Abc + aBc + abc Sterile Cretin (d)

The form of the table and the number of phenotypes is the same as previously, but the frequency of the various classes will be quite different. In this way we can express the linkage relationship of any two characters whether the individual characters are dependent on one, two or more factors. In all linkage considerations the symbols a, b, c and d stand for the frequencies of the cross-over and non-cross-over zygotic classes and not for theoretical phenotypes. Each of these classes may comprise several theoretical phenotypes.

Taking the simple case of two characters each segregating in 3 : 1 ratio, we find the following general formula to represent the relationship of gametic and zygotic series, as given by Emerson :—

$$3r^2 + \frac{2(s^2 + 2rs)}{a} : \frac{s^2 + 2rs}{b} : \frac{s^2 + 2rs}{c} : r^2 \quad d$$

This when expressed in terms of 'p', as already suggested, becomes

$$\frac{2 + p^2}{a} : \frac{p^2 - 1}{b} : \frac{p^2 - 1}{c} : \frac{p^2}{d}$$

This relationship holds good whether there is any linkage or not. Now, let us assume that there is no linkage and in such a case the value of  $p$  will be  $\cdot 50$  ( $50\%$ ) and that of  $p^2 = \cdot 25$ ; because when there is 50 per cent. cross-over, the natural result will be that all the gametes will be formed in equal numbers. When  $p = \cdot 5$ , the ratio of the classes  $a$ ,  $b$ ,  $c$  and  $d$  may be expressed as follows:

$$\begin{array}{cccccc} a : & b : & c : & d & & \\ 2 + p^2 & 1 - p^2 & 1 - p^2 & p^2 & & (1) \end{array}$$

$$\begin{array}{cccccc} 2.25 & 0.75 & 0.75 & 0.25 & & (2) \end{array}$$

$$\begin{array}{cccccc} 9 & 3 & 3 & 1 & & (3) \end{array}$$

which is a simple dihybrid ratio with no linkage. The relationship of the classes  $a$ ,  $b$ ,  $c$  and  $d$ , as given in the expression (1), will be true for all values of ' $p$ ', but the actual ratio will change with the value of ' $p$ '.

The ratio of the classes  $a$ ,  $b$ ,  $c$  and  $d$  may be numerically written from the expression (1), if we assume that there is no linkage, and  $p = \cdot 5$ . The converse of this will also be true, *i.e.* when we know the numerical ratio of the classes  $a$ ,  $b$ ,  $c$  and  $d$ , they can be expressed in terms of ' $p^2$ ' by assuming that  $p = \cdot 50$  and in this way we can obtain any number of expressions to represent the various phenotypic ratios obtained in Mendelian segregation of two characters.

Three general rules may be given on the basis of which we can express all types of ratios in terms of ' $p^2$ ':—

(i) In all cases where each of the two linked characters are determined by the presence of a single pair of factors or where one or both the characters are determined by Duplicate or Triplicate factors, we can represent the 4 different classes in terms of ' $p^2$ ' as shown below:—

TABLE VII.

Phenotypic ratio	CLASSES				REMARKS
	a	b	c	d	
(1) 3 : 1 and 3 : 1	9	3	3	1	(1) Actual ratio.
	2.25	.75	.75	.25	(2) Ratio in terms of .25 ( <i>i.e.</i> actual ratio divided by 4).
	$2 + p^2$	$1 - p^2$	$1 - p^2$	$p^2$	(3) Ratio in terms of $p^2$ (assuming $p^2 = \cdot 25$ ).

TABLE VII—*contd.*

Phenotypic ratio	CLASSES				REMARKS
	a	b	c	d	
(2) 15 : 1 and 3 : 1 .	45 11·25 11+p <sup>2</sup>	15 3·75 4—p <sup>2</sup>	3 0·75 1—p <sup>2</sup>	1 ·25 p <sup>2</sup>	(1) (2) (3)
(3) 15 : 1 and 15 : 1 .	225 56·25 56+p <sup>2</sup>	15 3·75 4—p <sup>2</sup>	15 3·75 4—p <sup>2</sup>	1 ·25 p <sup>2</sup>	(1) (2) (3)
(4) 63 : 1 and 3 : 1 .	189 47·25 47+p <sup>2</sup>	63 15·75 16—p <sup>2</sup>	3 ·75 1—p <sup>2</sup>	1 ·25 p <sup>2</sup>	(1) (2) (3)
(5) 63 : 1 and 15 : 1 .	945 236·5 236+p <sup>2</sup>	63 15·75 16—p <sup>2</sup>	15 3·75 4—p <sup>2</sup>	1 ·25 p <sup>2</sup>	(1) (2) (3)
(6) 63 : 1 and 63 : 1 .	3969 992·25 992+p <sup>2</sup>	63 15·75 16—p <sup>2</sup>	63 15·75 16—p <sup>2</sup>	1 ·25 p <sup>2</sup>	(1) (2) (3)

From the above table it is evident that the extreme classes 'a' and 'd' always have '+ p<sup>2</sup>', while the middle classes 'b' and 'c' have '— p<sup>2</sup>'. This is important to remember, as on it depends the permanent relationship of these classes. When the zygotes 'a' and 'd' are .75 of the total population, the zygotes 'b' and 'c' must be (1—.75) .25. On this fundamental principle the whole relationship exists. Further, we may note that in all the above cases (Table VII) the coefficient of 'p<sup>2</sup>' is always 1.

(ii) When, however, one of the characters is determined by two complementary factors and the other by duplicate or triplicate factors, the coefficient of 'p' is always 3. If the number of complementary factors increases, the coefficient of 'p<sup>2</sup>' also rises in geometric progression, i.e. with 2 complementary factors, the coefficient of p<sup>2</sup> is 3, with 3 complementary factors, the coefficient of p<sup>2</sup> is 3<sup>2</sup>, with 4 complementary factors, which is seldom realized in practice, the coefficient of p<sup>2</sup> is 3<sup>3</sup>. Thus in a general way, if 'n' represents the number of complementary factors involved in bringing about a character, the coefficient of

$p^2=3^{(n'-1)}$ . This will be more clear from the following table which gives various phenotypic ratios for two linked characters, one of which is determined by complementary factors and the other by single factor or by duplicate or triplicate factors:—

TABLE VIII.

Phenotypic ratio	Coefficient of $p^2$	Classes			
		a	b	c	d
(1) 9 : 7 and 3 : 1 .	$\begin{matrix} n'=2 \\ 3^{(n'-1)}p^2=3p^2 \end{matrix}$	$\begin{matrix} 27 \\ 6\cdot75 \\ 6+3p^2 \end{matrix}$	$\begin{matrix} 21 \\ 5\cdot25 \\ 6-3p^2 \end{matrix}$	$\begin{matrix} 9 \\ 2\cdot25 \\ 3-3p^2 \end{matrix}$	$\begin{matrix} 7 & (1) \\ 1\cdot75 & (2) \\ 1+3p^2 & (3) \end{matrix}$
(2) 9 : 7 and 15 : 1 .	$\begin{matrix} n'=2 \\ 3^{(n'-1)}p^2=3p^2 \end{matrix}$	$\begin{matrix} 135 \\ 33\cdot75 \\ 33+3p^2 \end{matrix}$	$\begin{matrix} 105 \\ 26\cdot25 \\ 27-3p^2 \end{matrix}$	$\begin{matrix} 9 \\ 2\cdot25 \\ 3-3p^2 \end{matrix}$	$\begin{matrix} 7 & (1) \\ 1\cdot75 & (2) \\ 1+3p & (3) \end{matrix}$
(3) 9 : 7 and 63 : 1 .	$\begin{matrix} n'=2 \\ 3^{(n'-1)}p^2=3p^2 \end{matrix}$	$\begin{matrix} 567 \\ 141\cdot75 \\ 141+3p^2 \end{matrix}$	$\begin{matrix} 441 \\ 110\cdot25 \\ 111-3p^2 \end{matrix}$	$\begin{matrix} 9 \\ 2\cdot25 \\ 3-3p^2 \end{matrix}$	$\begin{matrix} 7 & (1) \\ 1\cdot75 & (2) \\ 1+3p^2 & (3) \end{matrix}$
(4) 27 : 37 and 3 : 1	$\begin{matrix} n'=3 \\ 3^{(n'-1)}p^2=9p^2 \end{matrix}$	$\begin{matrix} 81 \\ 20\cdot25 \\ (18+2\cdot25) \\ 18+9p^2 \end{matrix}$	$\begin{matrix} 111 \\ 27\cdot75 \\ (30-2\cdot25) \\ 30-9p^2 \end{matrix}$	$\begin{matrix} 27 \\ 6\cdot75 \\ (9-2\cdot25) \\ 9-9p^2 \end{matrix}$	$\begin{matrix} 37 & (1) \\ 9\cdot25 & (2) \\ (7+2\cdot25) & \\ 7+9p^2 & (3) \end{matrix}$
(5) 27 : 37 and 15 : 1	$\begin{matrix} n'=3 \\ 3^{(n'-1)}p^2=9p^2 \end{matrix}$	$\begin{matrix} 405 \\ 101\cdot25 \\ (99+2\cdot25) \\ 99+9p^2 \end{matrix}$	$\begin{matrix} 555 \\ 138\cdot75 \\ (141-2\cdot25) \\ 141-9p^2 \end{matrix}$	$\begin{matrix} 27 \\ 6\cdot75 \\ (9-2\cdot25) \\ 9-9p^2 \end{matrix}$	$\begin{matrix} 37 & (1) \\ 9\cdot25 & (2) \\ (7+2\cdot25) & \\ 7+9p^2 & (3) \end{matrix}$
(6) 27 : 37 and 63 : 1	$\begin{matrix} n'=3 \\ 3^{(n'-1)}p^2=9p^2 \end{matrix}$	$\begin{matrix} 1701 \\ 425\cdot25 \\ (423+2\cdot25) \\ 423+9p^2 \end{matrix}$	$\begin{matrix} 2331 \\ 582\cdot75 \\ (585-2\cdot25) \\ 585-9p^2 \end{matrix}$	$\begin{matrix} 27 \\ 6\cdot75 \\ (9-2\cdot25) \\ 9-9p^2 \end{matrix}$	$\begin{matrix} 37 & (1) \\ 9\cdot25 & (2) \\ (7+2\cdot25) & \\ 7+9p^2 & (3) \end{matrix}$
(7) 81 : 175 and 3 : 1	$\begin{matrix} n'=4 \\ 3^{(n'-1)}p^2=27p^2 \end{matrix}$	$\begin{matrix} 243 \\ 60\cdot75 \\ (54+6\cdot75) \\ 56+27p^2 \end{matrix}$	$\begin{matrix} 525 \\ 131\cdot25 \\ (138-6\cdot75) \\ 138-27p^2 \end{matrix}$	$\begin{matrix} 81 \\ 20\cdot25 \\ (27-6\cdot75) \\ 27-27p^2 \end{matrix}$	$\begin{matrix} 175 & (1) \\ 43\cdot75 & (2) \\ (37+6\cdot75) & \\ 37+27p^2 & (3) \end{matrix}$

The coefficient of ' $p^2$ ' must always be the same in all classes, i.e. if class 'a' is represented by ' $9p^2$ ', the classes b, c and d must also have ' $\pm 9p^2$ '.

(iii) In cases where both the linked characters are determined by complementary factors, the phenotypic classes are represented in such a way that the coefficient of  $p^2$  is  $3^{(n'-2)}$ , where  $n'$  = the number of complementary factors involved.

TABLE IX.

Phenotypic ratios	Coefficient of $p^2$	Classes			
		a	b	c	d
(1) 9 : 7 and 9 : 7	$n'=4$	81	63	63	49 (1)
	$3^{(n'-2)}p^2=9p^2$	20.25	15.75	15.75	12.25 (2)
		(18+2.25)	(18-2.25)	(18-2.25)	(10+2.25)
		18+9p <sup>2</sup>	18-9p <sup>2</sup>	18-9p <sup>2</sup>	10+9p <sup>2</sup> } (3)
(2) 9 : 7 and 27 : 37	$n'=5$	243	333	189	259 (1)
	$3^{(n'-2)}p^2=27p^2$	60.75	83.25	47.25	64.75 (2)
		(54+6.75)	(90-6.75)	(54-6.75)	(58+6.75)
		54+27p <sup>2</sup>	90-27p <sup>2</sup>	54-27p <sup>2</sup>	58+27p <sup>2</sup> } (3)
(3) 27 : 37 and 27 : 37	$n'=6$	729	999	999	1369 (1)
	$3^{(n'-2)}p^2=81p^2$	182.25	249.75	249.75	342.25 (2)
		(162+20.25)	(270-20.25)	(270-20.25)	(322+20.25)
		162+81p <sup>2</sup>	270-81p <sup>2</sup>	270-81p <sup>2</sup>	322+81p <sup>2</sup> } (3)
(4) 81 : 175 and 9 : 7	$n'=6$	729	1575	567	1225 (1)
	$3^{(n'-2)}p^2=81p^2$	182.25	393.75	141.75	306.25 (2)
		(162+20.25)	(414-20.25)	(162-20.25)	(286+20.25)
		162+81p <sup>2</sup>	414-81p <sup>2</sup>	162-81p <sup>2</sup>	286+81p <sup>2</sup> } (3)

The frequency of the classes a, b, c and d expressed in terms of ' $p^2$ ', as given in Tables VII-IX, may also be arrived at by means of checkerboard, where linkage is assumed between any two factors, say A and C, and the intensity of linkage as ' $p$ '. Then the frequency of non-cross-over gametes will be ' $p$ ' and that of the cross-over gametes will be ' $1-p$ '. From this checkerboard of a 4-hybrid segregation we may write out all the phenotypes and their frequency in terms of ' $p^2$ ' as given in the following table:—

TABLE X.

Phenotypes	No. of factors present, i.e. $n'$	Frequency in terms of $p^2$	Frequency in terms of $p^2$ and $n'$
81 $^*(A)B(C)D$ . . .	4	$9p^2+18$	$3(n'-2)p^2+2.3n'^{-2}$
27 $(A)B(C)d$ . . .	3	$3p^2+6$	$3(n'-2)p^2+2.3n'^{-2}$
27 $(A)b(C)D$ . . .	3	$3p^2+6$	$3(n'-2)p^2+2.3n'^{-2}$
Cross-over classes, $\left\{ \begin{array}{l} 27 ABcD . . . \\ 27 aBCD . . . \end{array} \right.$	3	$9-9p^2$	$3(n'-1)-3(n'-1)p^2$
	3	$9-9p^2$	$3(n'-1)-3(n'-1)p^2$
9 $(A)b(C)d$ . . .	2	$p^2+2$	$3(n'-2)p^2+2.3(n'-2)$
$\dagger$ 9 $(a)B(c)D$ . . .	2	$9p^2$	$3(n')p^2$
Cross-over classes, $\left\{ \begin{array}{l} 9 ABcd . . . \\ 9 AbcD . . . \\ 9 aBCd . . . \\ 9 abCD . . . \\ 3 Abcd . . . \\ 3 abCd . . . \end{array} \right.$	2	$3-3p^2$	$3(n'-1)-3(n'-1)p^2$
	2	$3-3p^2$	$3(n'-1)-3(n'-1)p^2$
	2	$3-3p^2$	$3(n'-1)-3(n'-1)p^2$
	2	$3-3p^2$	$3(n'-1)-3(n'-1)p^2$
	1	$1-p^2$	$3(n'-1)-3(n'-1)p^2$
	1	$1-p^2$	$3(n'-1)-3(n'-1)p^2$
$\dagger$ 3 $(a)B(c)d$ . . .	1	$3p^2$	$3n'p^2$
$\dagger$ 3 $(a)b(c)D$ . . .	1	$3p^2$	$3n'p^2$
$\dagger$ 1 $(a)b(c)d$ . . .	0	$p^2$	$3n'p^2$

\* The bracketed factors are linked together.

$\dagger$  Both the linked factors are recessive in these Phenotypes and their frequency is represented in a slightly different form.

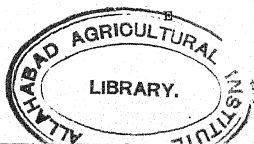
The fourth column of this table shows a constant relation between the frequency of the phenotypes in terms of  $p^2$  and the number of factors present in each phenotype. But this relationship differs in cross-over and non-cross-over classes. In the classes where linked factors remain together (*i.e.* non-cross-over) the coefficient of  $p^2$  is always  $+3^{n'-2}$ , while in the classes where the linked factors break up (*i.e.* cross-over) it is  $-3^{n'-1}$ . The frequency of the phenotypes, in which both the linked factors are recessive (marked  $\dagger$ ) is represented by  $3n' p^2$  only. On the basis of these formulæ, one can write out the phenotypic frequencies in terms of  $p^2$  of any Mendelian segregation without the trouble of checkerboard.

With the help of Table X, let us consider a case of linkage where both the characters are determined by duplicate factors AB and CD; the factors A and C being linked. In such a case, the four different classes will be :—

a	b	c	d
81 (A)B(C)D = $18+9p^2$ . 27 (A)B(C)d = $6+3p^2$ . 27 ABcD = $9-9p^2$ . 27 (A)b(C)D = $6+3p^2$ . 27 aBCD = $9-9p^2$ . 9 (A)b(C)d = $2+p^2$ . 9 AbcD = $3-3p^2$ . 9 aBCd = $3-3p^2$ . 9 (a)B(c)D = $9p^2$ .	9 ABed = $3-3p^2$ 3 Abcd = $1-p^2$ 3 (a)B(c)d = $3p^2$	9 abCD = $3-3p^2$ 3 abcd = $1-p^2$ 3 (a)b(c)D = $3p^2$	1 abcd = $p^2$
225 = $56+p^2$	15 = $4-p^2$	15 = $4-p^2$	1 = $p^2$

When one of the characters is determined by complementary factors and the other by duplicate factors, then the four different classes will be :—

a	b	c	d
81 (A)B(C)D = $18+9p^2$ 27 (A)B(C)d = $6+3p^2$ . 27 ABcD = $9-9p^2$ .	27 (A)b(C)D = $6+3p^2$ 27 aBCD = $9-9p^2$ 9 (A)b(C)d = $2+p^2$ 9 AbcD = $3-3p^2$ 9 aBCd = $3-3p^2$ 9 abCD = $3-3p^2$ 9 (a)B(c)D = $9p^2$ 3 abCd = $1-p^2$ 3 (a)b(c)D = $+3p^2$	9 ABed = $3-3p^2$	3 Abcd = $1-p^2$ 3 (a)B(c)d = $+3p^2$ 1 (a)b(c)d = $+p^2$
135 = $33+3p^2$	105 = $27-3p^2$	9 = $3-3p^2$	7 = $1+3p^2$



Similarly we can derive all the expressions given in tables VII to IX, but this lengthy process is not at all required after knowing the simple relationship that exists between the linkage-value 'p<sup>2</sup>' and the frequency of the classes a, b, c and d.

This lengthy method is analogous to the one adopted by Woodworth. It is given here simply to show how tedious is the process, still the results obtained are just the same as by the simple method already suggested.

For working out the frequency of the classes a, b, c and d by this short method, one has simply to write out the phenotypic ratios, assuming 50 per cent. linkage, and to divide each term of the ratio by 4. Then the frequencies could be expressed as  $x \pm p^{2*}$  or  $x \pm 3p^2$  or  $x \pm 9p^2$  etc. according to the nature of the factors involved in determining the linked characters (p. 48—51) and the nature of the classes, i.e. cross-over or non-cross-over. The cross-over classes always have '-p<sup>2</sup>' and the non-cross-over classes have '+p<sup>2</sup>'.

In the last few pages we have been more or less confined to the Coupling Phase only. All these formulæ and tables will hold good even for Repulsion Phase, only by slight alteration in the expression of cross-over and non-cross-over gametes, i.e. 'p' will represent the cross-over and '1-p' the non-cross-over gametes.

By the method suggested here, we can easily represent all the phenotypic classes in term of 'p<sup>2</sup>' and once this is done, it is very easy to calculate the value of 'p<sup>2</sup>' from any constant expressed in terms of the classes a, b, c and d by equating the two identities. This is further explained by taking a simple case of dihybrid segregation and deriving the formulæ for various constants dealt with in the foregoing pages. Thus—

Phenotypic ratio.	Classes.			
	a	b	c	d
3 : 1 and 3 : 1	$2+p^2$	$1-p^2$	$1-p^2$	$p^2$

Now, we may take some of the constants and express their value in terms of p<sup>2</sup> and in this way arrive at the formulæ suggested in this paper.

$$\text{Albert's Constant } k = \frac{16E}{n} \text{ or } \frac{16(a+d)}{a+b+c+d}$$

By substituting the value of a, b, c and d in terms of 'p<sup>2</sup>', we obtain

$$\begin{aligned} k &= \frac{16(2+p^2+p^2)}{2+p^2+1-p^2+1-p^2+p^2} = \frac{32(p^2+1)}{4} = 8(p^2+1) \\ &= 8p^2+8 \\ p^2 &= \frac{k-8}{8} \end{aligned}$$

$$\text{Similarly, the constant } P = \frac{ad}{bc} = \frac{(2+p^2)p^2}{(1-p^2)^2} = \frac{2p^2+4}{1+p^4-2p^2}$$

---

\*Where p<sup>2</sup>=.25 and the remaining whole number is represented by x.

This leads to a quadratic equation of the form

$$p^4(P-1) - p^2(2P+2) + P = 0$$

$$p^2 = \frac{(P+1) - \sqrt{3P+1}}{(P-1)}$$

It will be instructive to derive the formula given on page 24 in connection with the evaluation of linkage-value from Owen's<sup>1</sup> data on soybeans, where one of the zygotic classes is not recovered.

In this case  $P = \frac{a^2}{bc}$  (as explained on page 19)

$$= \frac{(11+p^2)^2}{(4-p^2)(1-p^2)} = \frac{121+22p^2+p^4}{4-5p^2+p^4}$$

This leads to a quadratic equation, where

$$4P - 5Pp^2 + Pp^4 - 121 - 22p^2 - p^4 = 0$$

$$p^4(P-1) - p^2(5P+22) + (4P-121) = 0$$

$$p^2 = \frac{(5P+22) - 3\sqrt{P^2+80P}}{2(P-1)}$$

In the same way we can work out the formulæ for all other constants expressed in terms of the classes a, b, c and d as given in the previous pages or even for a new one. The value of the classes a, b, c and d will, of course, be varying with the nature of the factors (*i.e.*, complementary or duplicate, etc.) involved, but the constants will remain the same. The value of these classes, in most cases, will be found from Tables VII to IX, but occasionally some workers may have to deal with quite different ratios and in that case they must express these values with the help of the general method given on pages 48 to 51. After representing these classes in terms of  $p^2$ , it will be a simple process to evaluate ' $p^2$ ' from the observed data with the help of any one method, all of which consist in equating the theoretical value of a certain constant to its observed value. The Product Ratio method, however, gives the best estimate and hence is recommended for general use.

A number of useful formulæ have already been given in Table V and others can easily be derived, if required, on the lines suggested in this paper.

## VII. SUMMARY AND CONCLUSION.

A number of methods for calculating linkage-values from an  $F_2$  population have been compared and their merits and demerits considered. The comparison of the various methods is based on tables similar to those suggested by Collins. Several examples from certain well-known data of linkage relationships have also been taken and the linkage intensities calculated by all the typical methods. The solutions obtained have been tested by the measure of discrepancy  $\chi^2$ .

<sup>1</sup> Owen (1928), *ib.*

These comparisons have established the superiority of the Product Ratio method over all others. This method was originally suggested by Dr. Fisher and is regarded as statistically efficient. Dr. Fisher, however, has presented it in a form that necessitates reference to a table of calculated values for Coupling and Repulsion. Such a table, which is applicable only to simple dihybrid ratios, has been given by him.

In order to make it generally applicable, the present writer has suggested several simple formulæ for calculating linkage-values directly from this Product Ratio. These formulæ may be readily applied to even complex Mendelian relationships. Hence this method and the formulæ are recommended for general use.

When one of the zygotic classes has not been recovered, all the methods fail to express a correct cross-over value; this is evident from Tables I to III. In such cases, however, the usual formulæ can be supplemented by a modification of the same as already given on pages 7 and 19. Thus a modification of the Product Ratio can be used with advantage even under these conditions.

The coefficient of correlation 'r' should be used only when the phenotypic ratios are very complicated and when there is no evidence of any differential viability of the zygotic classes.

The examples considered in this paper are specially interesting in serving as practical illustrations of the efficiency of the various methods. The inefficient methods give satisfactory results only under special conditions, while the efficient methods give accurate results under all conditions.

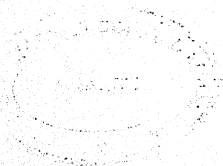
A few graphs have been given to illustrate the relationship of the cross-over percentage with the zygotic classes and also with the constants "P" and "k." These graphs show why in close Repulsion, it is difficult to arrive at an accurate recombination value.

A general method by which the value of ' $p^2$ ' can be found out from any constant expressed in terms of the zygotic classes a, b, c and d and for any zygotic distribution has been suggested at the end of the paper. It is expected that with the help of this, future workers can easily arrive at new formulæ applicable to their own special cases.

Memoirs, Botanical Series, Vol. XVI, No. 4, entitled "Further Studies of Indian Grasses and Grasslands".

Meaning of abbreviations in Plate IV, facing page 112.

A. c.	.	.	.	.	.	.	<i>Andropogon contortus.</i>
A. m.	.	.	.	.	.	.	<i>Andropogon monticola.</i>
A. f.	.	.	.	.	.	.	<i>Andropogon foveolatus.</i>
I. p.	.	.	.	.	.	.	<i>Ischaemum pilosum.</i>
I. l.	.	.	.	.	.	.	<i>Ischaemum laxum.</i>
Is. an.	.	.	.	.	.	.	<i>Isilema anthophoroides.</i>
Ar. r.	.	.	.	.	.	.	<i>Aristida redacta.</i>
Ar. f.	.	.	.	.	.	.	<i>Aristida funiculata.</i>
Ac. C.t.	.	.	.	.	.	.	<i>Acacia Catechu.</i>
Bs. lt.	.	.	.	.	.	.	<i>Bassia latifolia.</i>
Bs. sr.	.	.	.	.	.	.	<i>Boswellia serrata.</i>
T. Ar.	.	.	.	.	.	.	<i>Terminalia Arjuna.</i>



# ROOT DEVELOPMENT IN RICE UNDER DIFFERENT CONDITIONS OF GROWTH.

BY

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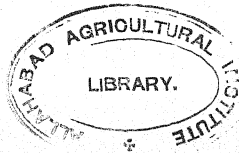
## INTRODUCTION.

In the course of my investigations into the different aspects of the growth of paddy in the United Provinces, it was found that most of the varieties could grow best only in their indigenous localities; and attempts to grow them in places away from their homes often resulted in failure. A change of locality brought about a change in the habits of growth and in the time of the ripening of the plant. To discover the factors which bring about these changes, the physiology of the rice plant had to be studied. This involved the study of the root and the relation of the root system to the soil-type. For a scientific understanding of crop-production, an exact knowledge of the facts relating to the development of the root system also appeared necessary. Such knowledge is essential before the manner in which the soil and the crop are connected can be appreciated. This study of rice-roots is important to scientific agriculture, specially as no work has yet been done in this direction. An attempt is made in this paper to deal with this subject:—the broad facts of root-distribution and the root-relation of the rice plant to important soil-types and manures; and the effect on root development of important factors like soil-texture, soil-moisture, soil-aeration and soil-temperature.

## REVIEW OF LITERATURE OF EARLIER WORKERS.

The above ground portions of plants generally have received considerable attention, but a study of the underground root system has not been attempted to the same extent. A beginning was, however, made towards the end of the nineteenth century in the United States of America, when the root systems of species of different plant communities, widely separated geographically and growing under distinctly different climatic conditions, were studied. The results of these exhaustive studies have been published by Prof. John E. Weaver.<sup>1</sup> The names of King (1892), Headen

<sup>1</sup> Weaver, J. E. Publications of the Carnegie Institution of Washington, United States of America, Nos. 286, 292 and 316 for 1919, 1920 and 1922, respectively.



(1896), Goff (1897), Ten Eyack (1899, 1900, 1904) and Shepherd (1905) at Wisconsin, Colorado, Kansas and North Dakota Agricultural Experiment Stations, respectively, may be mentioned as a few of the earlier important workers on this line. In 1916 Miller<sup>1</sup> studied the root system of corn and the *sorghums* at the Kansas Agricultural Experiment Station, United States of America. In 1917 the Howards<sup>2</sup> at Pusa conducted a series of investigations on the root development of different crops. In 1921, Brechley and Violet G. Jackson<sup>3</sup> carried on investigations of the root development of wheat and barley at Rothamsted. In 1922, Venkatraman and Thomas<sup>4</sup> carried on some extensive work on the study of root development of sugarcane at Coimbatore. But no attempt has so far been made to study the development of the root system of the rice plant.

#### PRACTICAL METHODS OF STUDY.

(a) *Employed by other workers.* The workers in the United States of America dug trenches, two to three feet wide and six to ten feet long, to a depth of about six feet by the sides of the plants to be examined. The trenches were deepened as the work progressed and the root system was excavated almost in its entirety. The operations sometimes extended over a field several square miles in extent. Work on such an elaborate scale cannot possibly be attempted by men with limited resources.

Miller's method consisted of the isolation of a prism of soil containing the plant whose root system was desired and then placing over this block of earth a wire cage of such a shape and size as to fit closely to the vertical sides of the block. Numerous small wires were then run through the prism of earth and fastened to each side of the cage. When the earth was washed away by means of a stream of water, the main roots remained suspended on the cross wires in the same position that they occupied in the soil. According to the author himself, this method was open to criticism, firstly because the main roots of the plant may not be in the prism of the soil which was isolated, and, secondly, it was impossible to retain all the finer roots in their normal position, although the primary roots of the plant remained on wires in the same position that they occupied in the soil.

Brechley and Jackson tried trenching in the field in barley, but on account of the hard soil, it was difficult to wash out the roots without breaking them. To obviate this difficulty, a cube of soil was dug out with selected plants in the middle of it and this solid block was transferred to a box which just held it. The box was brought down to the laboratory and the roots were washed with a stream of water.

<sup>1</sup> Miller, E. C. Comparative study of the root systems and leaf areas of corn and the *Sorghums*. *Jour. of Agri. Res.*, Vol. VI, 1, 1916, p. 311.

<sup>2</sup> Howard, A. and G. L. C. The Economic significance of root development of Agri. crops. *Agri. Jour. of India*, Vol. XII, 1917.

<sup>3</sup> Brechley, W. E., and Jackson, Violet G. Root development of wheat and barley under different conditions of growth. *Annals of Bot.*, Vol. XXXV, 1921, p. 533.

<sup>4</sup> Venkatraman, T. S., and Thomas, R. Sugarcane root system: studies in development and anatomy. *Agri. Jour. of India*, Vol. XVII, Part IV, July 1922.

The method employed by Venkatraman and Thomas consisted in excavating trenches beforehand in places where it was intended to grow the plant whose root system was to be studied. The chief defect about this cheap and simple method is that it is applicable only to plants specially grown for the purpose.

(b) *Employed by the author.* (i) *In the field.* A rice field about the size of half an acre with one of its margins elevated above the adjacent fields was selected for experimental purpose. The field was divided into eight equal blocks and in each block a trench, six feet long, six feet wide and six feet deep, was dug at the end close to the elevated margin. These excavations were then refilled with the soil taken out, taking care to replace the layers in the same position in which they were removed. At the time of filling these trenches horizontal layers of six inch wire netting, cut to the required size, were placed at three levels for catching the growing root strands. The blocks, including the trenched pieces, were prepared and puddled in an ordinary way and different manures were added to each block at the rate shown in Table VII. Thus, the trenched pieces were also prepared along with the rest of the field, the only difference being that their soils were loosened beforehand and wire netting was spread underneath. Plants that were selected for the study of the root development under different treatments were those that were growing on these trenched areas. At the time of washing these plants, a deep pit was dug round the other three sides of the trenched plot and a block of earth was thus separated from the rest of the field. This could be easily washed from the open face side of the elevated margin. The washing was done with the help of a patent "Four Oaks Knapsack Sprayer." Skilled labourers were, however, using hand picks for loosening the earth during the washing process. Thus the whole root system, when excavated, was held *in situ* by the wire netting. After jotting down notes, the roots were extricated from the wire netting and photographed (Plate III). Out of about half a dozen plants that were growing on the trenched area, only two that approximated the average plants of the whole block were selected for recording observation. Although the trenched piece of land is disturbed by excavation and is not left in so natural condition as the rest of the field, yet great care was taken to treat the plot in the same way as the remaining field. The condition therefore approximated to the natural conditions. It would be still better, however, if a better method could be devised for studying the details of the roots under ordinary puddled conditions of a rice field. This is an interesting point and deserves further attention.

(ii) *In the pots.* The washing here was easy in the beginning with the smaller vessels. These were broken, the substance held in hand, and washed carefully under a jet of water from a slow running tap. The blocks of earth were small in size and could be easily handled. The clay blocks were, however, put in water for a few hours, before washing, for softening the earth. The plants were extricated without damaging the roots. A wire net was also held underneath the pots for catching bits of roots that might be broken during washing. This was necessary

to get at the actual dry weight of the roots. Later on with larger earthen pots, and with wooden boxes, it was found impracticable to empty the contents without damaging the delicate roots, and the method employed was different. The vessels were placed in a horizontal position on a stand of convenient height, the two parallel sides of the box were removed and the soil was washed out by means of a small, but fairly strong, jet of water. The machine which was used in the field was also employed here. In pots where it was intended to study the natural spread of the root system, horizontal layers of wire netting of half an inch mesh, cut to the size of the pot or the box, were inserted at different levels at the time of filling them with earth. The roots were held by the wire netting, and the whole system photographed (Plate II).

#### EXPERIMENTAL METHODS.

Before describing the outline of the work, it is desirable to give the climatic data of the place where the study was made. Table I shows a portion of the summary of air temperatures (F°) for the growing season of 1926.

TABLE I.

*Air temperature (in shade) F° at the Botanical Farm, Cawnpore.*

Month	Mean average temperature									
June	.	.	.	.	.	.	.	.	.	97
July	.	.	.	.	.	.	.	.	.	88
August	.	.	.	.	.	.	.	.	.	85
September	.	.	.	.	.	.	.	.	.	84
October	.	.	.	.	.	.	.	.	.	79
November	.	.	.	.	.	.	.	.	.	66
December	.	.	.	.	.	.	.	.	.	61

Table II gives the number of inches of rainfall during 1926.<sup>1</sup> The figures are compared with the normal.

TABLE II.

*Rainfall (in inches) at the Botanical Farm, Cawnpore (1926-27).*

FROM APRIL 1ST TO AUGUST 31ST			FROM SEPTEMBER 1ST TO OCTOBER 31ST			FROM NOVEMBER 1ST TO MARCH 31ST			TOTAL		
Normal	1926	No. of rainy days	Normal	1926	No. of rainy days	Normal	1926-27	No. of rainy days	Normal	1926	No. of rainy days
23.63	20.07	26	6.48	8.89	11	1.74	1.00	3	31.85	29.96	40

<sup>1</sup> Season and Crop Report of United Provinces, Government Press, Allahabad, 1926-27.

Table III shows the mechanical and chemical analysis of the farm soil, and Table IV, the analysis of the soils used in the pot experiments. The field-soil was a typical Gangetic alluvium, allowing little subsoil drainage.

TABLE III.

*Soil analysis of the paddy fields of the Botanical Farm, Cawnpore.*

*(a) Mechanical analysis.*

Coarse sand	Fine sand	Shk	Fine silt	Clay	Moisture	Loss on ignition	CaCo <sub>3</sub>
0.70	48.74	27.44	21.46	8.79	3.00	3.86	0.89

*(b) Chemical analysis.*

Soluble and insoluble silica	% Moisture	% Organic matter	% N	% K <sub>2</sub> O	% Na <sub>2</sub> O	% CaO	% Fe <sub>2</sub> O <sub>3</sub> & Al <sub>2</sub> O <sub>3</sub>	% P <sub>2</sub> O <sub>5</sub>	% MgO	% CaCo <sub>3</sub>	% SO <sub>2</sub>
79.48	3.00	3.86	0.05	1.73	0.57	1.20	11.27	0.45	0.16	0.89	0.08

TABLE IV.

*Chemical analysis of soils used in pots.*

	% N.	% P <sub>2</sub> O <sub>5</sub>	% CaO
Clay . . . . .	0.028 °	0.34	0.12
Gravel . . . . .	0.006	0.20	0.18
Sand . . . . .	0.002	0.25	0.20

GENERAL OUTLINE OF WORK.

The experiments were conducted during the summer of 1926 at the Botanical Farm, Cawnpore. The plants were grown in cylindrical earthen vessels and in field. These furnished the material for a study of the relative dry weights of the roots and the aerial portions of the plants. Smaller vessels of nine inch height and eight and a half inch diameter, holding about thirteen and a half lb. of soil, were

employed for earlier observations. Bigger pots and wooden boxes of much larger capacity were, however, employed for later observations. Different soils were employed in the vessels and different manures were added. The varied nature of treatment is shown in Tables V and VI.

The seeds of the following four pure varieties were used in the experiments :—

*Early types* (early ripening, generally sown broadcast).

- (i) Coarse oval-shaped spikelets—colour at ripening dull brown with mottlings of deep brown.
- (ii) A little late in ripening as compared to (i). Spikelets medium shaped (Ellipsoid), neither coarse nor fine. Colour at ripening orange red.

*Late types* (late ripening, generally transplanted).

- (iii) Spikelets of fine long shape—colour at ripening ordinary yellow.
- (iv) A little late in ripening as compared to (iii). Coarse oval-shaped spikelets. Colour at ripening deep brown.

Each variety was sown under ten different conditions. The examination of roots was made six times on the dates shown in Tables V and VI. Forty plants, *i.e.*, four kinds under ten different treatments, were examined each time. The observations were made once fortnightly in the beginning and at longer intervals later on. Seeds were sown in the pots on the evening of the eighth of August. One plant was allowed to grow in each pot. Near the ripening stage, there were chances of accidental loss due to the basal dried leaves blowing off by wind or to the falling down of deciduous spikelets. This was avoided by covering the heads altogether by means of a thin muslin bag above and loosely tying a thread around the stem of plant below. The roots after washing were put in a big glass jar, full of water, and notes were taken of the condition of root development. Afterwards, the whole plant was dried first in the sun, later in a steam oven, and the dry weights of shoots and roots were obtained separately. The last observations of both early and late kinds were made on ripe plants, after a total period of three months and nineteen days after sowing in the former and four months and thirteen days in the latter.

## I. OBSERVATIONS ON POT CULTURES.

*Extent of the root system.* After about a fortnight's growth, the root system of rice consisted of two distinct types :—

- (i) Long, thin, flaccid, light brown and much branched roots.
- (ii) Bold, white, comparatively short, almost unbranched roots of waxen appearance.

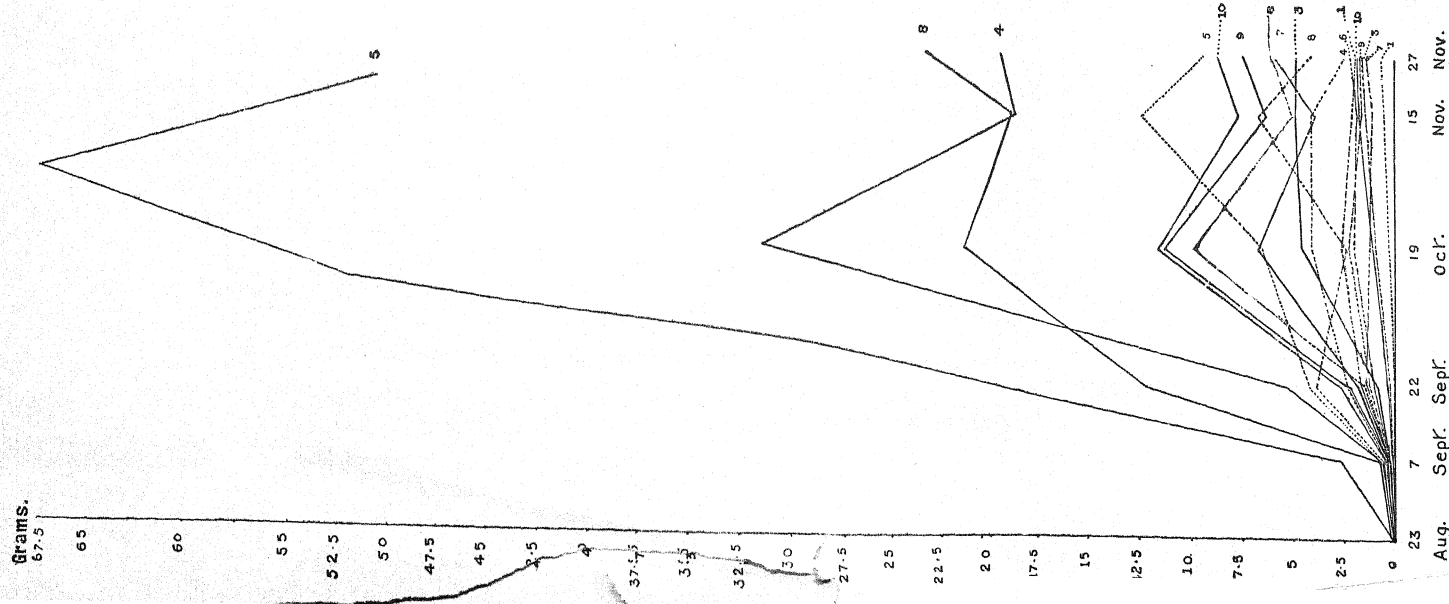
The development, however, of both types of roots varied according to soil used manurial treatment and the varieties sown as follows :—

*Soil* (Plates I and II). During the first fortnight of growth, the roots in clay were thick, white and unbranched. In <sup>clay</sup>/<sub>sand</sub> there were thick white roots in the

upper clay half and thin branched in the lower sand half. It was the other way with the reversed strata in <sup>sand</sup>clay. The white bold roots showed their maximum development in clay. Roots in loam were poorer allround than in clay and were less spreading. In gravel and sand they were finer in nature than in other soils and showed poor branching. Afterwards when the plants were examined half way through growth, the root system was found better developed. There was a greater development of fine thin lateral branches in the entire root system. Clay had developed fine lateral branches, although the white bold roots still existed in large numbers. The change of the type of root system with the change of strata in <sup>clay</sup>sand and <sup>sand</sup>clay had become less pronounced by the development of lateral branches in bold white roots of the clay beds. Roots in loam were better than before, but were still poorer in growth as compared to clay. Roots in gravel were slightly bolder than those in sand. One distinction between these two was, however, markedly noticeable. Roots in sand were straight, while those in gravel were wavy. This phenomenon was visible throughout. The effect of different soil-textures, in the absence of any manure, is thus quite apparent. Sand or gravel on one end of the scale, and clay on the other, with loam in the intermediate position, showed a characteristic effect of their own on the development of roots. They were fine, silky and sparsely branched in sand; thick, white, tough and well-developed in clay and possessed an intermediate character in loam (Plate I).

*Manure.* The development in size and length of the roots was directly proportional to the amount of nitrogenous food available and the presence of moisture in the soil. The roots were showing their maximum growth in ammonium sulphate and farmyard manure, where many secondary branches with fine lateral development formed a profusely branched thick mat. Ammonium sulphate roots were of a more spreading nature than that of the farmyard manure. The growth of the root system in the latter series was weak in the beginning, but nearly approached the former towards the end. Roots in superphosphate and muriate of potash were poorer as compared to nitrogenous manures. In the former they were of a more spreading nature than in the latter, where they remained lanky.

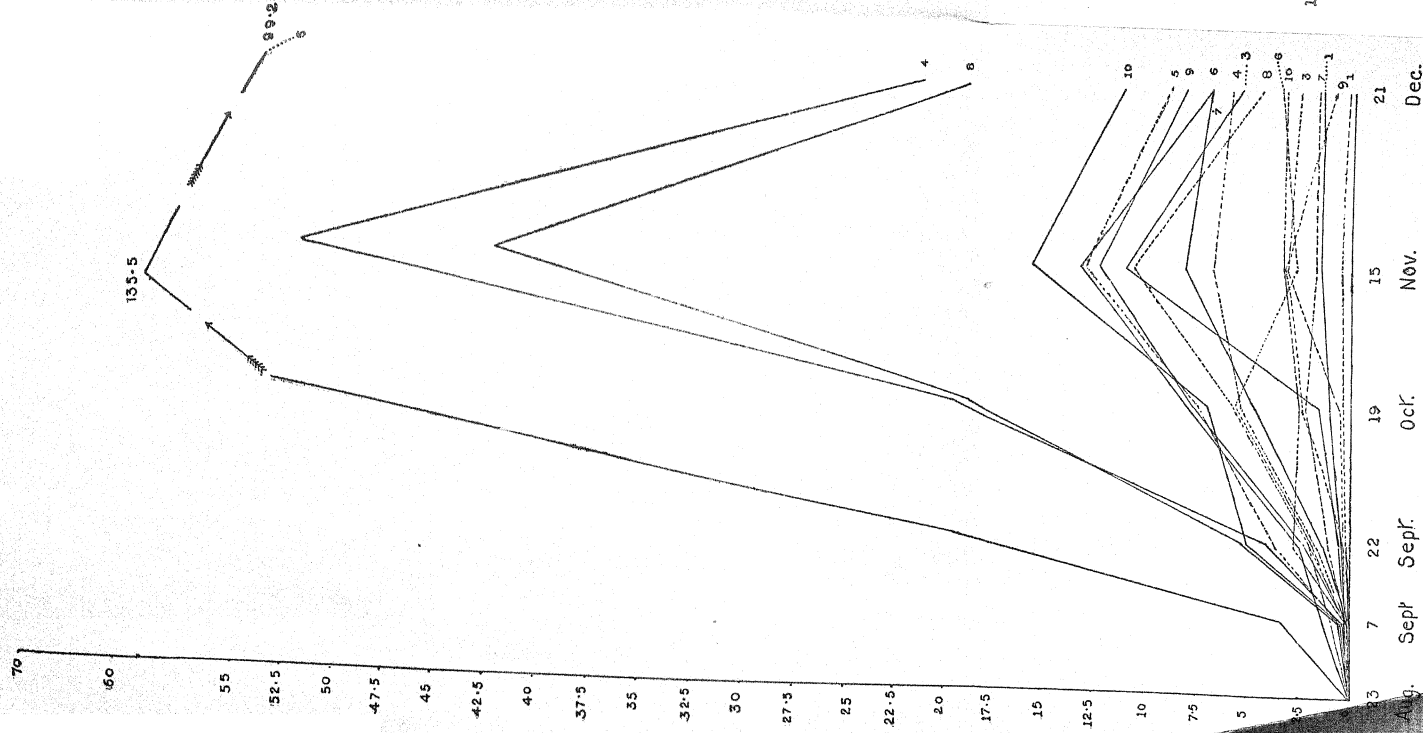
About the white roots in general—these were longer and thinner in nature in the nitrogenous manures than in pure clay, although their total number was greater in the former than in the latter. These white roots did not retain their unbranched character throughout the life of the plant, but, about a month and a half after sowing, they put out laterals, and ultimately approximated to the general root system. At the time of the appearance of flowers, a marked change was noticed in the entire root system. The thick white bold roots were no longer present and the whole root system now became weak and flaccid. This phenomenon occurred sooner in the unmanured series than in the manured ones. The behaviour of clay in this respect was like that of a nitrogenous manure. In certain plants it occurred even when the flowers were within their leaf sheaths. In many cases, such as in farmyard manure, ammonium sulphate and clay, even after the appearance of this



Early plants grown in pots—dry weights of shoots plain lines.  
dry weights of roots-dotted lines. (Mean of two plants in each case.)

Fig. 1. Graphical representation of Table V.

Grams.



Late plants grown in pots - dry weight's of shoots plain lines,  
dry weight's of roots-dotted lines. (Mean of two plants in each case)

Fig. 2. Graphical Representation of Table VI.



on roots in farmyard manure, in gravel and in sand. Roots of the farmyard manure series were, however, of a dull white colour, while those of the other two were of shining bright appearance. A transverse section showed that the colour was deposited in a layer just below the epidermis. That this colour was probably due to more clay and moisture in the soil was corroborated from observations made on soils with different constituents. A sample of soil from Tulsipur with 21.50 per cent. of clay under constant irrigation developed deep red brown colour on the roots of the plants grown in it, while another from Doiwala with 12.10 per cent. of clay and under comparatively less irrigation did not show any colour on the roots. The colour thus appeared to be an indirect indication of the presence of more clay and moisture in the soil.

*Penetration.* The length of the roots was also measured at different stages of their growth to find out the difference in penetration under various treatments. In pots the average range of penetration, without manure, lay between two and three feet. It was ten to eighteen inches in the beginning and reached its maximum of thirty to forty inches after flowering. The majority of the roots was found within the first one or two feet, and only a few ran to the length of three or occasionally four feet. Much depended on the food and other environmental factors. The easiest penetration was found in gravel and sand, where even within a fortnight's growth, the roots had grown long and thin, and were seen coiling round the bottom of the pots. This is in accordance with the views of Benecks,<sup>1</sup> who states that scarcity of nutrients has a tendency to increase the root length. The penetration was found the least in clay in the beginning, but it was the greatest in the end. It was quicker in the beginning in early kinds than in late kinds, while near the harvest the roots of late kinds were comparatively longer than the early kinds. In farmyard manure and ammonium sulphate, due to the greater development of lateral branching and the consequent diversion of energy of the plant in that direction, the penetration was not found exceeding three feet.

The penetration in the field, on the other hand, was not so great in a vertical direction as those of the pot plants. The roots tended to go off at an angle, running more or less horizontally, with a downward inclination, taking advantage of an easier passage wherever available. Also the root development was, on the whole, comparatively less in the field; the manured and unmanured series behaved alike in this respect.

*Relative growth of shoot and root.* (Tables V and VI and Figs. 1 and 2.) The relative weights of shoot and root of individual rice plants, at different periods of growth, were obtained from the amount of the dry matter produced. In the beginning for about a month after sowing, the growth was slow both in early and late kinds, and there was not much difference in the dry weights, either between shoots and roots, or under different treatments. Later, however, their growth proceeded rapidly and the effect of different manures (which reached its maximum,

<sup>1</sup> Benecks. Carnegie Insti. Publication by Prof. J. E. Weaver, No. 292, 1920, p. 97.

## STUDIES IN ROOT DEVELOPMENT IN RICE

TABLE V.

*Dry weights of individual rice plants (early varieties) sown in earthen pots on 8th August 1936 (weights without ears).*

	GRAVEL			SAND			LOAM (UNFERTILIZED)			LOAM + FARMYARD MANURE (MIXED IN EQUAL QUANTITIES)			LOAM + AM. SULPHATE		
	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.
22nd August. (After 15 days.)	0.018 0.022	0.012 0.018	0.030 0.040	0.015 0.035	0.018 0.026	0.033 0.061	0.035 0.065	0.028 0.028	0.061 0.063	0.038 0.058	0.012 0.024	0.050 0.052	0.082 .108	0.035 0.055	0.117 0.163
7th September. (After one month.)	.115 0.082	0.055 0.025	0.178 0.157	0.082 0.066	0.024 0.016	0.106 0.082	0.095 .110	0.022 0.045	0.120 0.158	.348 .562	.108 .272	0.546 .884	2.248 2.648	.382 .588	2.630 3.246
22nd September. (After 13 months.)	.140 .120	0.070 0.080	0.210 0.200	Dead.	Dead.	Dead.	.428 .382	.292 .368	.620 1.100	5.109 4.971	2.100 2.300	7.209 7.271	13.781 17.260	3.965 4.265	17.746 21.524
19th October. (After 2 months and 11 days.)	Dead.	Dead.	Dead.	Dead.	Dead.	Dead.	4.930 3.960	.875 .595	5.805 4.575	23.020 20.840	3.468 4.422	36.718 24.262	53.780 49.920	5.261 7.589	59.041 66.859
15th November. (After 3 months and 7 days.)	Dead.	Dead.	Dead.	Dead.	Dead.	Dead.	3.965 5.785	.960 1.822	4.975 7.175	17.860 19.870	3.110 5.180	20.970 25.000	63.139 69.141	10.812 14.488	73.451 83.629
27th November. (After 3 months and 19 days.)	2.030 2.000	.460 .410	2.520 2.560	Dead.	Dead.	Dead.	4.320 5.470	1.250 1.160	5.670 6.660	18.880 20.040	1.982 2.028	20.862 22.968	47.908 51.082	8.977 9.608	56.875 60.745

TABLE V.

*Dry weights of individual rice plants (early varieties) sown in earthen pots on 8th August 1926 (weights without ears).*

	LOAM SUPERPHOSPHATE.			LOAM + MURIATE OF POTASH			CLAY			CLAY SAND (UPPER HALF OF POT AND LOWER HALF WITH SAND)			SAND CLAY (REVERSE OF SAND)		
	Shoot Gm.	Root Gm.	Total Gm.	Shoot Gm.	Root Gm.	Total Gm.	Shoot Gm.	Root Gm.	Total Gm.	Shoot Gm.	Root Gm.	Total Gm.	Shoot Gm.	Root Gm.	Total Gm.
28th August. (After 15 days.)	0.073 0.082	.025 .044	0.100 0.076	0.082 0.042	0.027 0.023	0.059 0.075	0.020 0.010	0.050 0.041	0.059 0.041	0.037 0.023	0.031 0.019	0.068 0.042	0.042 0.004	0.049 0.031	0.091 0.123
7th September. (After one month.)	.420 .680	.102 .148	.522 .778	.329 .511	.179 .191	.408 .462	.200 .210	.600 .620	.600 .620	.210 .250	.113 0.067	.323 .347	.109 .231	.201 .279	.400 .510
22nd September. (After 1½ months.)	1.102 1.018	.832 1.068	1.934 2.980	1.223 2.207	1.010 1.050	2.233 3.347	2.013 4.787	14.823 16.977	14.823 16.977	1.006 2.545	.008 1.202	2.964 3.747	1.869 3.251	.072 1.038	2.871 5.219
19th October. (After 2 months and 11 days.)	8.248 11.788	2.174 1.076	10.516 13.774	4.998 8.842	.910 1.340	5.908 9.682	1.078 2.722	21.764 25.016	21.764 25.016	10.879 11.941	2.988 1.792	13.867 13.783	10.822 12.968	1.899 3.041	12.791 16.409
43th November. (After 3 months and 7 days.)	4.351 5.379	.461 1.949	5.282 7.528	3.275 4.655	1.009 .771	4.284 5.426	5.410 7.840	22.131 28.929	22.131 28.929	5.939 6.501	1.100 1.400	7.039 7.901	6.014 8.396	2.153 1.987	9.067 10.383
27th November. (After 3 months and 19 days.)	6.032 5.988	.073 2.007	7.035 8.655	4.703 6.867	.872 1.108	5.605 7.975	4.922 3.978	27.134 27.766	27.134 27.766	6.078 7.862	1.218 2.287	8.191 10.179	7.395 6.005	1.218 2.968	9.427 12.923



TABLE VI.

*Dry weights of individual rice plants (late varieties) sown in earthen pots on 8th August 1926 (weights without ears).*

	LOAM SUPERPHOSPHATE			LOAM MULCH OF POTASH			CLAY			CLAY SAND (UPPER HALF OF POT FILLED WITH CLAY AND LOWER HALF WITH SAND)			SAND CLAY (REVERSED OF CLAY)		
	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.	Shoot Grm.	Root Grm.	Total Grm.
22nd August. (After 15 days.)	0.096 -114	0.081 0.040	0.177 0.153	0.030 0.057	0.052 0.048	0.091 0.105	0.038 0.022	0.038 0.048	0.076 0.070	0.070 0.038	0.068 0.018	0.068 0.054	0.051 0.053	0.019 0.041	0.070 0.155
7th September. (After one month.)	1.310 1.320	0.788 0.327	1.973 2.047	0.274 0.256	1.132 1.185	0.886 0.854	0.044 0.038	0.120 0.170	0.164 0.308	0.149 0.321	0.072 0.108	0.231 0.429	0.01 0.429	0.119 0.351	0.730 0.810
22nd September. (After 1½ months.)	2.432 2.048	2.062 2.018	4.194 4.066	0.938 1.472	1.17 0.83	1.108 2.302	1.508 0.872	5.001 4.800	7.109 5.771	2.988 1.862	8.90 1.480	2.276 3.382	4.971 5.140	2.109 2.311	8.980 7.460
10th October. (After 2 months and 11 days.)	6.897 9.808	4.976 6.811	11.273 16.217	2.872 3.467	2.960 2.408	5.832 7.867	4.639 6.761	20.860 28.060	20.860 28.060	5.231 9.090	1.821 2.730	7.042 12.048	5.112 8.988	1.212 3.688	6.324 12.076
15th November. (After 3 months and 7 days.)	11.860 14.701	2.117 2.019	14.016 16.720	6.057 8.323	2.170 1.920	8.227 9.813	8.221 11.939	48.460 41.211	28.060 59.100	13.431 11.050	2.404 1.736	16.835 18.125	12.871 18.080	2.797 4.023	15.668 22.712
24th December. (After 4 months and 13 days.)	7.050 6.880	2.973 3.967	10.023 10.947	6.482 7.668	1.310 1.851	7.801 9.419	3.688 5.157	17.689 50.451	21.972 55.708	7.663 8.917	1.432 0.908	9.235 9.975	0.688 12.082	2.991 3.649	12.979 16.541

in the majority of cases, about two and a half months after sowing in early, and three months in late, kinds) was distinctly noticeable. The lack of proportion between the growth of shoot and root was more marked in clay, and in nitrogenous manures than elsewhere. The growth of shoot was at its maximum a little after flowering in both the varieties, in almost all the series, but there was a difference of growth in the two kinds near the harvest time. In the early kinds, there was maximum growth of shoot after two and a half months' time after sowing. With the appearance of flowers (sixty-four days after sowing) there was a fall in the weights of shoots as seen after three months and seven days. After the flowers were set, an increase again was seen near the harvest time as shown after three months and nineteen days. It is obvious, therefore, that the intervening set-back in the shoot-growth was due to much of the material being translocated towards the flowering region during that period. After the flowers were set (the material being again diverted towards the vegetative region), an increase in the dry weight of the shoots, although not to the same extent as before flowering, became evident. This agrees with Sen's<sup>1</sup> observation that during the flowering stage, when the "milk" is forming in the grain, there occurs a translocation of the dry matter from the stem and leaves to the flowers.

In late kinds, on the other hand, once the maximum development was reached, the energy of the plant was probably so much exhausted at the flowering stage (flowered eighty-six days after sowing) that not much material was left for translocation to the aerial regions, and to increase the weight of the shoots again near the harvest period. Most likely, this was influenced by the temperature of the atmosphere, which might have checked further growth. That temperature has a marked influence in checking further growth was confirmed by observations made in the field. The plants did not show any reduction in their weights, either in pots or in field, till late in November in the early, and about a month after in the late, kinds; in other words, when the season had become cold.

Thus in the early kinds the shoot-weights continued to increase after a fall, but in the late kinds, on the other hand, the weights having once fallen, did not show any further increase near the harvest. But the early varieties grown in ammonium sulphate behaved differently. Their behaviour resembled late varieties in showing a steady decrease of shoot-weights towards the harvest period. An explanation of this may be found in the fact that ammonium sulphate tended to prolong the growth of the early crop, and thereby made an early variety behave like a late variety.

The development of roots was in almost all cases found to be directly proportional to the development of shoots. Like the shoot development, it was better in late kinds, in clay soils and in nitrogenous manures. In gravel the data during earlier observations are left blank, as many plants were found dead, and a few living

<sup>1</sup> Sen, J. N. A study in the assimilation of nutrients by the rice plant. *Agri. Res. Inst. Pusa Bull.* 65, 1916.

ones were left for recording observations near the end. In sand the plants could not survive up to the last date of observation. They died sooner than in other conditions. Generally speaking, the roots were bright and strong up to the time when the flowers were forming within the leaf-sheath. They became flaccid afterwards. This flaccidity, however, did not stop their further growth, which proceeded though slowly after flowering. A decrease from their maximum in the weights of roots was noticed in all the series near the harvest.

## II. OBSERVATIONS ON FIELD TRIALS (TABLES VII AND VIII).

A few experiments were also conducted in the field to find out, in general, the difference in growth in the pot and in the field condition, as well as to corroborate the results achieved in the pots. Two sets of experiments were arranged:—(i) under different manurial treatments, (ii) under different conditions of cultivation. In order to spread the work over a fairly long period, plants were examined from each of these sets on different dates. Seeds were sown, as in the pots, in the first, while the seedlings were transplanted in the second set. The weights of plants of these sets, therefore, do not show equal growth on the same dates. They, however, afford data to show the comparative growth of plants under different conditions presented by a particular set. Two average plants representative of a particular experiment were, however, selected for recording observations. In set No. 1 plants were grown under different manurial treatments (Table VII and Plate III). In addition to the manures which were employed in the earthen pots, plants were also treated with organic manures like castor (*Ricinus communis* L.) and neem cake (*Azadirachta indica* Juss.) and were green manured with sannhemp (*Crotalaria juncea* L.). The method of excavating roots has already been described. Green manuring showed the best result, closely followed by the oil-cakes. The effect of other manures on the development of white bold and flaccid roots, laterals and colours was similar to that seen in the pot cultures. Under similar treatments, the growth in the field, in general, was poorer than that in the pots. The development of fine above ground ramifications of the roots running parallel to the surface was greater in the field than in the pots, probably because of the more free play of water and the presence of more algae. It appeared more pronounced in the oil-cakes and ammonium sulphate beds than in farmyard manure and unmanured series. Also the root system in the beds under these nitrogenous manures developed nearer the surface level than in the unmanured bed, where the roots developed at a depth of about two to six inches below the surface level. This concentration of the root system near the surface level in the manured beds may be due to the presence of a greater quantity of oxygen, in a dissolved condition in the surface film of algae. This film of algae according to Harrison and Subramania Aiyar<sup>1</sup> is the chief agent

<sup>1</sup> Harrison, W. H., and S. Aiyar. Gases of swamp Rice soils. *Mem. Dept. Agri. India, Chem. Ser.*, Vol. III, 1913, part II.

in causing the aeration of the roots of the rice crop. The location of the actual seat of absorption, whether by means of root hairs or other parts of roots, is a matter of importance and is under further investigation.

TABLE VII.

*Dry weights of average individual rice plants under different manurial treatments in the field (early variety sown broadcast on 8th August 1926—weights without ears).*

Treatment	20TH OCTOBER		
	Shoot gram.	Root gram.	Total gram.
1.			
<i>Sanai (Crotalaria juncea)</i>	41.320	4.921	46.241
(Seed sown at the rate of 60 lb. per acre).	44.040	6.499	50.539
2.			
Castor cake	36.912	3.822	40.734
(15 maunds per acre).	41.518	6.838	48.356
3.			
Neem cake	33.719	4.111	37.830
(15 maunds per acre).	40.121	6.389	46.510
4.			
Ammonium sulphate	32.833	2.921	35.754
(160 lb. per acre).	35.877	4.760	40.646

TABLE VII—*contd.*

*Dry weights of average individual rice plants under different manurial treatments in the field (early variety sown broadcast on 8th August 1926—weights without ears)—contd.*

Treatment	20TH OCTOBER		
	Shoot gm.	Root gm.	Total gm.
5.			
Farmyard manure	18-718	2-170	20-888
(100 maunds per acre).	25-082	3-450	28-532
6.			
Superphosphate	6-982	1-310	8-292
(120 lb. per acre).	7-348	1-970	9-318
7.			
Muriate of potash	4-722	1-108	5-830
(100 lb. per acre).	7-038	1-130	8-168
8.			
Unmanured.	3-438	-412	3-850
	3-105	-517	3-622

1 maund = 82 lb.

In the second set of experiments (Table VIII), cubes of soil were dug out from the rice field to get the root system. These cubes were fairly big and of uniform size, but did not accommodate all the roots running obliquely. Thus while the dry weights of these roots do not show their total weights, they give a fair idea of the comparative development of the root system under different conditions of cultivation. In the United Provinces rice is generally sown in the nursery in early June, and transplanted in early July with the break of the monsoon. After the harvest of the *rabi* (spring crop), some lands are left untouched, while others are constantly

stirred by plough during the hot weather. Plants were sown in both kinds of land. On comparison, it was found that the ploughed piece of land produced better plant and root system than the one which was left uncultivated. In the ploughed plots the roots were running more or less parallel to the surface level, and showed a wider spread than in the unploughed plot, where the roots were running more vertically downwards.

TABLE VIII.

*Dry weights of individual rice plants under different conditions of cultivation. (Late variety sown on 5th June 1926, transplanted on 25th July 1926.)*

	Date	Shoot	Root	Total		Shoot	Root	Total
		grm.	grm.	grm.		grm.	grm.	grm.
1. With hot weather cultivation.	24th August.	3-214	310	3-524	Without cultivation.	9-62	158	1-120
		4-446	550	4-996		1-298	282	1-580
	24th September.	19-971	2130	22-101		10-321	359	10-680
		20-629	3-110	23-739		12-869	1-291	14-070
	24th October. (Lower figures yield-mean of two plants.)	22-911	2-983	25-894		16-312	977	17-289
		23-659				17-348		
		16-200	3-465	27-124		12-820	1-223	18-571
2. Under constant irrigation.	24th August.	8-213	1-210	9-423	Alternate drying and irrigation.	3-214	310	3-524
		9-707	1-650	11-357		4-446	550	4-996
	24th September.	28-391	2-983	31-370		19-971	2-130	22-101
		30-709	4-242	35-041		20-629	3-110	23-739
	24th October. (Lower figures yield-mean of two plants.)	42-832	3-980	46-813		22-911	2-983	25-894
		43-807				23-659		
		16-085	5-120	48-927		16-200	3-465	27-124
		(Bad ripening, many ears empty and damaged.)						

Further the roots of plants from the ploughed piece of land were compared with the roots of the plants grown in a piece of land which was kept under constant irrigation, the former condition corresponding to the system of alternate drying and

irrigation. The water in the bed under constant irrigation was kept more or less in a standing condition and was sparingly changed. While the development of shoots and roots under constant irrigation was better, the yield was lower, the ripening was far from uniform and many ears were found empty. Constant irrigation appeared to produce the same effects as excessive nitrogenous manuring, namely of prolonging vegetative growth and inducing irregular ripening. This is in accordance with the views of Hall,<sup>1</sup> who says that there is an association of high nitrogenous manuring with susceptibility to disease and irregular ripening. The roots under constant irrigation developed more of the white thick bold types in early life and more of the red brown colour in old flaccid condition than those of the other bed.

#### GENERAL DISCUSSION OF THE RESULTS.

The study of the root system affords us a knowledge of the environmental conditions most suited for rice cultivation. These are discussed as under :—

*Soil texture.* Plates I and II demonstrate in a striking manner the effect of soil texture on the growth of a rice plant. Also we have seen that under similar conditions roots showed better development in the pots than in the field. The reason for this may be partly due to the better texture of soil in the former case. In pots the soil was carefully sifted and shaken into position. It was friable, well aerated and moist, and as the watering was done regularly, the plants did not suffer either from drought or excess of moisture. In the field, on the other hand, the texture was not good, as the soil below six to eight inches from the surface was more consolidated than the upper layers. Warth<sup>2</sup> also states that soil texture exerts a more marked effect upon the yield of paddy than the soil reaction, or the presence of large or small amounts of food.

*Soil temperature.* Cannon<sup>3</sup> states that, during the warmer days of winter and early spring, the superficial soil attains a relatively high temperature, while the deeper soil is yet cold. The conditions for most favourable water absorption were, therefore, not present in winter, and the effect was a limitation of the development of both roots and shoots. Reversed conditions were to be found in summer, when the lower soil layers at the time of rains were warmer than the upper soil layers. The conditions of growth of both shoots and roots in the summer were, therefore, most favourable. This is fully borne out by the results of these experiments. The retarding effect of cold has already been discussed. The comparative better development in pots may also be due to the more favourable conditions of temperature there than in the field. The pots being relatively small and exposed on all sides to air, it could safely be assumed that the temperature of the soil at

<sup>1</sup> Hall, Sir A. D. Fertilizers and manures, page 136.

<sup>2</sup> Warth, F. J. Notes on the soil of the Expt. Farms. *Dept. of Agri. Burma Bull.* 13, 1916, p. 5.

<sup>3</sup> Cannon, W. A. The root habit of desert plants. *Carnegie Inst. of Washington*, 1911, No. 131, p. 88.

the bottom and at the top in the pot approximated more closely than the temperature at the bottom and at the surface of the soil in the field.

*Soil moisture.* This is also an important factor in influencing the growth of the rice roots. Cannon<sup>1</sup> states that the depth to which the roots of the annuals penetrate the ground is directly controlled by the depth of penetration of the rains of the season and the persistence of the annuals is mainly and directly dependent on the length of time the water remains in the soil where they are growing. According to Miller<sup>2</sup> the soil moisture content and the amount of available plant nutrients are important factors in determining the ratio of the weights of the top of plants to their root weights. Kiesselback<sup>3</sup> found the ratio of the weight of top to that of root to be 8.5 for corn plants grown in soil, with a water content of 98 per cent., and 5.2 for plants growing in soil with a water content of 20 per cent. These conclusions are also borne out by observations made in these experiments. The greatest growth in pure clay soil without the addition of any manure is probably due to the retentivity of moisture which is obviously more here than in any other soil. Also it was repeatedly seen in the field that the maximum growth of the root system was found within the first six to twelve inches of the surface soil. Although no definite data of the water movement at that depth were available, it could be safely assumed that during the period of greatest growth the soil at that depth had an adequate water supply and provided practically all the water necessary for the plants and that it was only afterwards, when by progressive drying out the upper soil was too dry for benefiting the plant, that it obtained its water from lower levels at greater depth. Plants also under constant irrigation, although they were poorer in yield, produced greater growth than the plants under alternate irrigation and drying (Table VIII).

*Soil aeration.* The importance of this factor in the root development has been explained by the Howards.<sup>4</sup> They found that soil aeration was essential for the proper development of the root system. According to them the only way by which a low-lying rice field can get its soil water aerated is by a slow passage of fresh oxygenated water past the roots. Again according to Cannon and Free,<sup>5</sup> one of the beneficial effects of heavy rains, apart from the increased water-content, specially in heavy soils, is the increased oxygen supply to the plant roots, rain water being a solution highly charged with oxygen and having a markedly stimulating effect upon growth. Confirmation of this was also obtained from the results of these experiments. The pots which were regularly supplied with fresh water throughout

<sup>1</sup> Cannon, W. A. *Ibid.*, p. 90.

<sup>2</sup> Miller, E. C. *Ibid.*, p. 324.

<sup>3</sup> Kiesselback, T. A. Transpiration Expt. with the corn plant. *Nebr. Agri. Expt. Stn., U. S. A., 23rd Ann. Rep.*, 1919, pp. 125-139.

<sup>4</sup> Howard, A. and G. L. C. *Ibid.* Also soil erosion and surface drainage, *Penn. Agri. Res. Inst. Bull.*, 53.

<sup>5</sup> Cannon W. A., and Free. Weaver's publication by Carnegie Inst. Washington, No. 292, 1920, p. 96.

showed better growth of roots than the field, which depended almost entirely on irregular rains. Cannon<sup>1</sup> found that deep-rooted plants were less dependent on good aeration than shallow-rooted ones. No comparison was made with any deep-rooted plant, but rice, a shallow-rooted plant, responded fairly to the favourable conditions of penetrability and aeration under pot-culture conditions.

The influence of various environmental factors on the root system discussed above reveal certain points of economic significance. We find that clay is the best soil both as regards texture and retentivity of moisture, that a certain degree of temperature of both soil and atmosphere is necessary for proper development, and that a change of water for oxygenating and aeration are the most important factors for the healthy development of the roots of the rice plant. Further, the study of the root system gives information on two more points. Firstly, it helps in distinguishing different varieties from one another. Although wide variations occurred within a type, through the influence of various environmental factors as presented by the field and the pot cultures, yet it was found that the general type of the root system was more or less a constant character of the type concerned. We have seen with regard to the variety No. (iii) of the late types, which showed a marked difference in root development under different soils, that its roots were finer in nature throughout under all conditions than those of the other three kinds. Again, variety No. (iv) of the late kinds, which was late in ripening as compared to the others, showed the greatest growth of the root system. Generally it was observed that the development of the roots was in proportion to the time of ripening; latest ripening varieties showed greatest development of their roots. Cannon<sup>2</sup> also states that the roots of any species act consistently, and where the conditions are much changed, still the induced variation is superimposed on the specific and familiar habit in such a way that the proper habit is easily recognised.

Secondly, it tells us the best time for providing the food elements to the plant. We have seen that before the flowering stage, the roots are bright and strong, but with the appearance of reproductive growth, the roots start showing flaccidity. This obviously means a reduction of strain on the roots. The greatest part of the work of the roots, therefore, is finished before the flowering period. Consequently, the elements of food material must be provided during the early period of the life of the plant. This is in accordance with the views of Sinor E. Herrero<sup>3</sup> who states that, with the appearance of flowers, the whole of the plant's energy is directed towards grain formation. According to him the assimilation of nitrogen, phosphoric acid and potash in the rice plant is fairly complete by the time the flowers appear and enough food must be available for the plant during the early stage.

<sup>1</sup> Cannon, W. A. Relation of root growth and development to the temperature and aeration of soil. *Amer. Jour. of Bot.*, II, No. 5, pp. 211-224.

<sup>2</sup> Cannon, W. A. The root habit of desert plants. Carnegie Inst. of Washington, 1911, No. 131, p. 87.

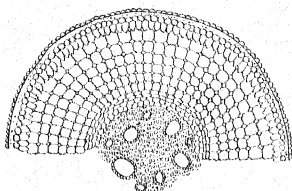
<sup>3</sup> Herrero, Sinor E., Paper read at the International Sci. Congress at Valencia, reproduced by E. J. Butler. *Agri. Jour. of India*, Vol. IX, 1914, p. 338.

## ANATOMY OF ROOTS.

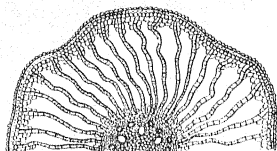
Fig. 3 illustrates the anatomy of roots of the rice plant (*Oryza sativa*). The layer of cells below the epidermis is thick-walled. In old flaccid roots it shows

## Anatomy of Roots.

NR 1.

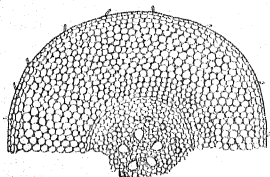


NR 2.

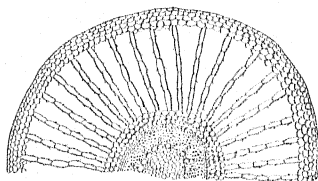


T.S. Through a Young bold white root (*Oryza sativa*) T.S. Through an old Flaccid root (*Oryza sativa*)

NR 3.



NR 4.



T.S. Through a Young root of wheat (*Triticum vulgare*) T.S. Through a root of a water plant (*Eichornia crassipes*)

Fig. 3. Anatomy of the roots of *Oryza sativa* L. compared with the anatomy of a land and a water plant of the same Natural order.

impregnation with reddish brown colouring matter. The central parenchymatous tissue is also thick-walled, as compared with the walls of the cells of the cortical region. Generally five to six vascular bundles are present in a well developed white bold root. The number may increase in old roots, but their size is slightly smaller than in the bold young roots.

A comparison of the anatomy of the root of the rice plant has been made with that of wheat and water hyacinth (*Eichornia crassipes*)—a typical land and a typical

water plant of the same order. We find that the features of the young white bold root (No. 1) resemble the former, while that of the old flaccid root (No. 2), the latter. Big air chambers are present only in the cortex of the old roots. The middle cortex, as seen in the transverse section, consists of radial plates of cells like the spokes of a wheel, separated by lacunae. We know that roots perform a great part of their work before the flowering stage and also the assimilation of nutrients is almost complete by that stage. White roots predominate during that period of life time. These roots are devoid of air chambers and are not typical water plant roots, but are similar to ordinary dry land crop roots like that of wheat. As such they require aeration, if their healthiness is to be maintained. This is in accordance with the view expressed by Brizi<sup>1</sup> in Italy who states that the roots of the rice plant do not conform to the aquatic type, and showed by means of water cultures that aeration was absolutely essential for their growth. The presence of a lacunar system in the old flaccid roots, according to Agnes Arber,<sup>2</sup> may be attributed to the theory of inheritance of acquired characters. She states that there is no doubt that the habit of developing an elaborate aerating system has now become, in many cases, an inherited character, for though it can be modified and reduced by terrestrial conditions, it cannot be eliminated. Thus, it seems that the rice grown in the plains of the United Provinces are not quite aquatic plants as is usually inferred from the fact that the crop requires much water and is generally grown under swamp conditions. The anatomy of roots shows that they require aeration for the healthy growth of the plant.

My thanks are due to P. Paijanti Prashad, L.Ag., for the help rendered in washing the root and in taking measurements.

#### SUMMARY.

1. Studies of the root system of the paddy plant under varying conditions of growth have been made.
2. A résumé of the methods for excavating the root system as employed by other workers is given and the one employed by the Author is also described.
3. Two types of roots were noticed during the life time of the plant—(a) thin, brown, flaccid, branched roots; (b) bold, white, almost unbranched. Their development, lateral branching, penetration, colouration produced on them as influenced by different soils, manurial treatment and varieties sown are described.
4. The development of the root system was bright and strong before flowering. It became weak and flaccid with the appearance of the flowers. All food elements should, therefore, be provided before flowering when the root system is at its best to carry on its function properly.
5. Studies have been made in the field as well and the results are compared with those in the pots.

<sup>1</sup> Brizi. Views quoted by Harrison, W. H., and S. Ayer. *Ibid.*, Vol. III, part III.

<sup>2</sup> Arber, Agnes. Water plants, Cambridge University Press, 1926, p. 194.

6. Root development shows distinguishing diagnostic characters for each variety which could be of help in the selection of varieties suited to particular localities.

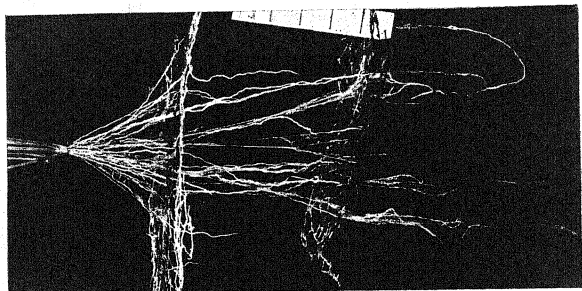
7. The texture of clay seems to suit the root development better than that of loam, gravel and sand.

8. Temperature exerts a marked influence. Summer and rainy seasons appear to be the most suitable periods for growth, while cold has an inhibiting action on growth.

9. The greater the moisture content, the better the growth but slower is the ripening.

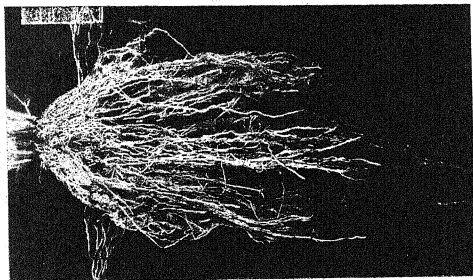
10. Anatomical observations show that the rice plant is not quite an aquatic plant as is usually inferred from the fact that it requires much water and is generally grown under swamp conditions. Aeration is absolutely essential for the healthy development of the plant.

Fig. 3.



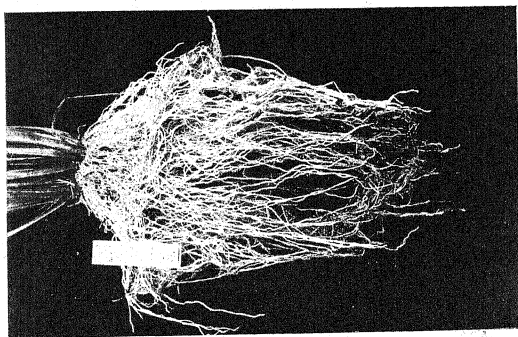
Gravel

Fig. 2.



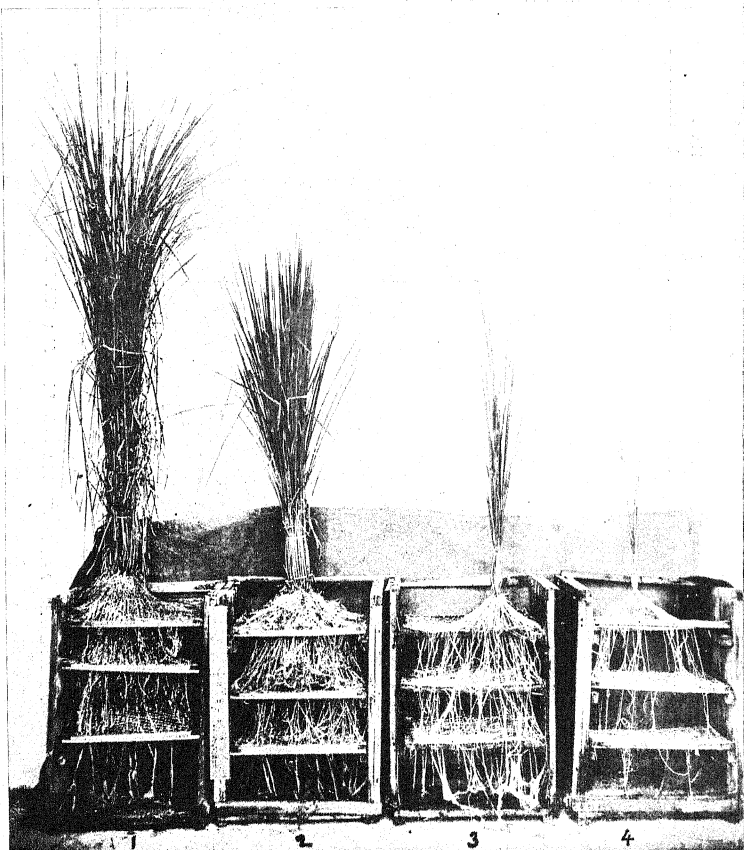
Loam

Fig. 1.



Clay

ROOT DEVELOPMENT IN DIFFERENT SOILS IN POTS (EARLY GROWTH).



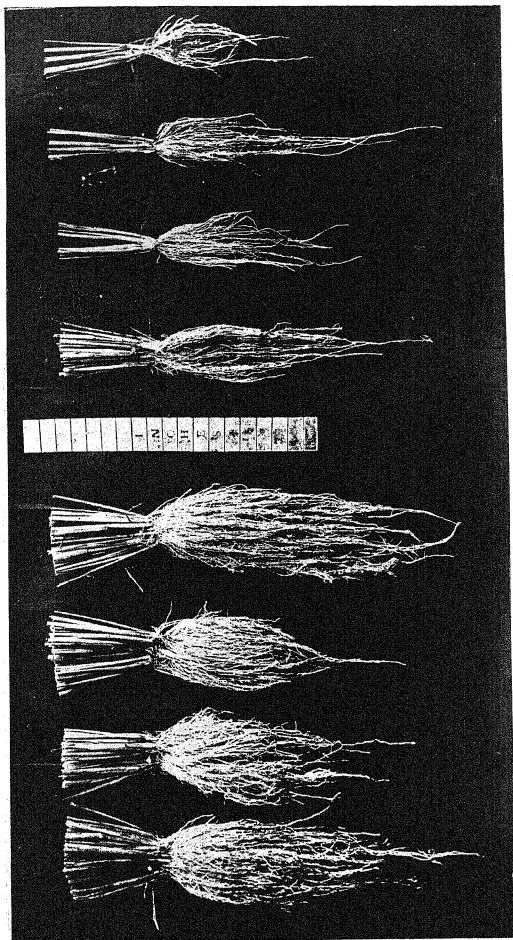
Clay

Loam

Gravel

Sand

ROOT DEVELOPMENT IN DIFFERENT SOILS IN WOODEN BOXES (LATE GROWTH).



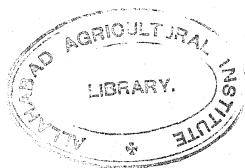
ROOT DEVELOPMENT UNDER FIELD CONDITIONS UNDER DIFFERENT MANURIAL TREATMENTS.

1, Castor cake; 2, *Neem* (*Azadirachta indica*) cake; 3, Ammonium sulphate; 4, Green manure with *Crotalaria Juncea*; 5, Farmyard manure; 6, Superphosphate; 7, Muriate of potash; 8, Unmanured.



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# STUDIES IN INDIAN OIL SEEDS

## No. 3. *Carthamus tinctorius* Linn.

### The Types of Safflower.

BY

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(Received for publication on 28th June 1929.)

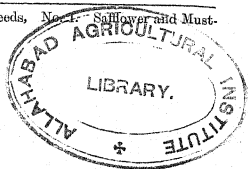
#### I. Introduction.

Safflower (*Carthamus tinctorius* Linn.) has been under investigation at Pusa since 1908. The results of the earlier investigations with this crop have already been published in a Memoir<sup>1</sup> containing the descriptions of 24 types which were isolated from seed obtained from Bombay, Sind, Bihar and the United Provinces. The present paper contains the descriptions of ten additional types which have been isolated from seed obtained from Dacca and from Behea near Patna. These ten types are quite distinct from those previously described and the present paper must be regarded as a supplement to the original Memoir. Work on the isolation of these types was started by the writer in 1918 under the instructions of Mr. A. Howard, the then Imperial Economic Botanist. Most of the selections were splitting natural hybrids and took a long time to become fixed. Since 1926, however, they have been found to breed true to type.

#### II. Morphological Characters.

The morphological characters of the original 24 types of safflower have been described by Howard, Howard, and Abdur Rahman Khan who state that the classification of types is relatively easy as they vary greatly in general habit, leaves, bracts and inflorescence. These authors classify the original 24 types into two main sections according to the shape of the outer bracts and the presence of spines on the outer bracts. Further subdivision of these sections is based on the hairiness of the bracts and the colour of the florets. The first four of the ten new types (Nos. 25, 26, 27, 28) are spinose and fall next to types 5 and 6 in the first section of this classification; the remaining six new types are spineless and constitute a third division of the second section.

<sup>1</sup> Howard, Howard, and A. R. Khan. Studies in Indian Oil Seeds, No. 1. Safflower and Mustard. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. VII, No. 7, 1915.



The following description of the morphological characters which form the basis of the classification is taken from the previous Memoir :—

“ *Habit.* The great differences met with in general habit depend on the height, on the angle at which the secondary branches are given off and also on the point on the main stem where branching begins. The range in height of the various types is considerable, the limits in 1914 being 100 and 170 cm. The general angle at which the secondary branches arise from the main stem also shows a wide range from rather dwarf, spreading, well-branched plants to tall forms in which the branches are close to the stem. Approximate measurements of these angles showed that the limits were  $15^{\circ}$  to  $45^{\circ}$ . The habit is also influenced by the point on the same stem at which branching begins. The open, spreading forms begin to branch low on the stem, about 5 cm. from the ground, while the tall forms of closer habit do not give off their first laterals below 30 cm. from the base.

“ *Leaves.* The large, lower leaves, which are always practically free from spines, vary greatly as regards the margin and the extent of division.<sup>1</sup> The margin usually ranges from wavy to deeply dentate, while in some types the leaves are entire, in others they are divided almost to the midrib. In the late types, the internodes near the base are very short and in these there appears to be a tuft of radical leaves; in the earlier forms, the internodes are more evenly distributed. In all the types, the leaves diminish in size from below upwards and, in all \* cases, the upper leaves are more or less spinose. In some types, however, the spines are very small while in others they are highly developed and are both long and numerous. In the massed habit, the differences in leaf-colour between the types become evident. The tone varies from light to a very dark green.

“ *Bracts.* In the involueral bracts there is also a great range in form (Plate I).† In all the types, the outer bracts are constricted above the base and are always foliaceous and often spinose. The basal imbricated portions of the bracts are without spines but these are more or less developed on the foliar part above the constriction. There are great differences among the types in the size, shape, indentation and degree of development of the spines of the foliar portions of the involueral bracts. Those types with spinose upper leaves develop this character in the bracts, while in the almost spineless forms the spines on the bracts are few and short. In some types, the lower imbricated portions of the bracts are covered with soft white hairs, in others, these are nearly absent and the unopened buds look green. The hoary or green appearance of the capitulum is a remarkably constant character and one that has been made use of in classifying the types.

“ *Florets.* The colour of the florets varies from whitish to almost red (Plate II).‡ Between these extremes, yellowish and slightly reddish intermediate types occur. These differences arise from the yellow and red colouring matters in

<sup>1</sup> The large lower leaves of all the types are illustrated on Plate I at the end of the present Memoir.

\* In some of the new types the upper leaves are entirely spineless.

† See *Mém. Dept. Agri. India, Bot. Ser.*, Vol. VII, No. 7, 1915.

the floret and the degree to which the red colour is developed can be seen both in the unopened buds and in the faded corollas."

### III. Description of the new Types.

*Type 25.* Intermediate as regards time of maturity, height 114 cm., habit somewhat erect. Lower leaves  $22 \times 8$  cm., oblanceolate, incised, rather dark green. Inflorescence leaves lanceolate, spinose-serrate with long spines. Outer involucre bracts leafy, constricted above the base, lanceolate with long spines; inner bracts narrower,  $4.2 \times 1.2$  cm. Florets deep yellow in the bud with a red dot on the apex, yellow when open, fading to orange red.

*Type 26.* Very early, height 80 cm., habit spreading. Lower leaves  $18 \times 5$  cm., oblanceolate, dentate, dark green. Inflorescence leaves lanceolate, spinose-serrate with long spines. Outer involucre bracts leafy, constricted above the base, lanceolate with long spines; inner bracts narrower,  $3.8 \times 1.2$  cm. Florets deep yellow in the bud with a red dot on the apex, yellow when open, fading to orange red.

*Type 27.* Very early, height 100 cm., habit spreading. Lower leaves  $19 \times 5$  cm., oblanceolate, dentate, light green. Inflorescence leaves lanceolate, serrate with long spines. Outer involucre bracts leafy, constricted above the base, lanceolate with long spines; inner bracts narrower,  $3.8 \times 1.0$  cm. Florets deep yellow in the bud with a red dot on the apex, yellow when open, fading to orange red.

*Type 28.* Very early, height 113 cm., habit spreading. Lower leaves  $20 \times 6$  cm., oblanceolate, dentate with long teeth, light green. Inflorescence lanceolate, spinose-serrate with long spines. Outer involucre bracts leafy, constricted above the base, lanceolate with long spines, inner bracts narrower,  $3.6 \times 1.3$  cm. Florets deep yellow in the bud with a faint red dot on the apex, yellow when open, fading to orange red.

*Type 29.* Very early, height 106 cm., habit very erect. Lower leaves  $16 \times 5$  cm., oblanceolate, serrate, very dark green. Inflorescence leaves lanceolate, spineless, entire. Outer involucre bracts leafy, constricted above the base, lanceolate or sometimes elliptical, spineless; inner bracts narrow and smooth. Florets deep yellow in the mature bud with a very faint red spot on the apex and red streaks and patches on the sides, yellow without red spot when open, fading to red.

*Type 30.* Intermediate as regards time of maturity, height 125 cm., habit erect. Lower leaves  $15 \times 4$  cm., oblanceolate, dark green. Inflorescence leaves lanceolate, spineless, entire. Outer involucre bracts leafy, constricted above the base, lanceolate or rarely elliptical, spineless; inner bracts narrow and smooth. Florets deep yellow in the mature bud with a red dot in the apex, yellow when open, fading to red.

*Type 31.* Very early, height 97 cm., habit spreading. Lower leaves  $15 \times 4$  cm., oblanceolate, serrate, dark green. Inflorescence leaves lanceolate, spineless, entire. Outer involucre bracts leafy, constricted above the base, lanceolate or rarely elliptical, spineless; inner bracts narrow and smooth. Florets deep yellow in the mature

B. Flower buds deep yellow with no red dot.

a. Flower buds with red streaks, leaves dark green . . . Type xxxii.

b. Flower buds without red streaks, leaves green.

1. Plants early . . . . . Type xxxiii.

2. Plants intermediate in maturity . . . . . Type xxxiv.

### V. Oil Content of the Seed.

Although the importance of safflower as a dye-yielding plant has been considerably affected by the introduction of the aniline dyes, the crop is still of importance as a source of oil.<sup>1</sup>

The percentage of oil in the seed of Types 1 to 24 was determined first in 1915<sup>2</sup> and again in 1925. The later determinations show generally a slightly higher value for the oil content (Table I); this may be attributed generally to seasonal variation although in the case of Types 1 and 22 the differences between the two determinations are evidently outside the limits of fluctuating variation. The oil percentage in the seed of new types was determined for the first time in 1925 and again this year, when Type 1 and Type 22 were also included in the analyses. At present no explanation can be given for the marked variation in the oil percentage recorded for Types 1 and 22. In the new types those isolated from the Dacca seed possess generally small seeds and a low content; they are, however, rich in carthamin and are spineless. This latter character may render them useful as a fodder crop.

TABLE I.

*Oil content of the types of Indian safflower.*

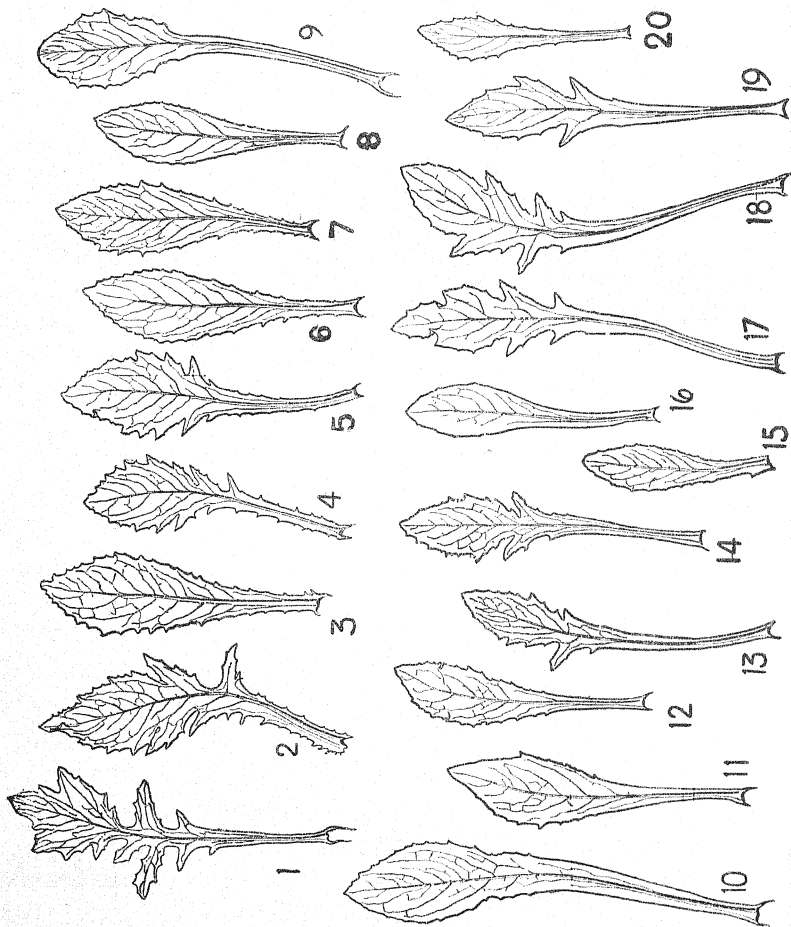
Type	WEIGHT OF 100 SEEDS IN GRAMMES			PERCENTAGE OF OIL		
	1915	1925	1929	1915	1925	1929
1 . . . . .	6.1	6.32	..	13.86	32.50	29.36
2 . . . . .	4.4	3.95	..	26.86	32.41	..
3 . . . . .	5.6	4.57	..	24.12	28.18	..
4 . . . . .	3.9	3.67	..	25.60	29.95	..
5 . . . . .	4.5	4.31	..	27.26	29.16	..
6 . . . . .	5.1	5.36	..	26.77	26.67	..
7 . . . . .	5.0	5.97	..	30.19	27.44	..

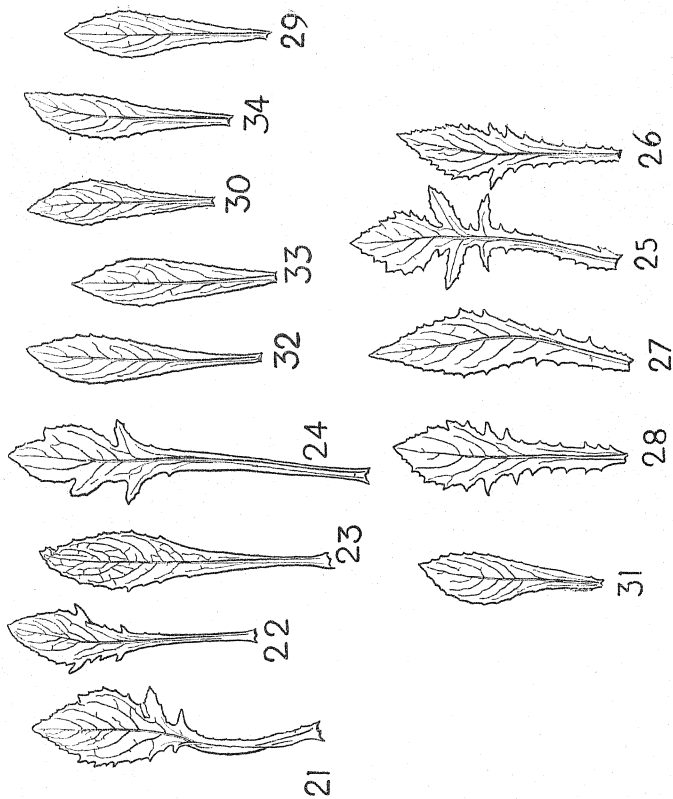
<sup>1</sup> Howard, A., and Remington, J. S. Safflower Oil. *Agr. Res. Inst. Pusa., Bull.* 124, 1921.  
*loc. cit.*

*Oil content of the types of Indian safflower—concl'd.*

Type	WEIGHT OF 100 SEEDS IN GRAMMES			PERCENTAGE OF OIL		
	1915	1925	1929	1915	1925	1929
8 . . . . .	4.2	4.41	..	24.00	24.09	..
9 . . . . .	4.8	3.95	..	27.99	29.73	..
10 . . . . .	4.2	3.83	..	25.54	30.43	..
11 . . . . .	3.2	3.37	..	28.19	30.07	..
12 . . . . .	5.1	4.80	..	27.18	28.76	..
13 . . . . .	4.0	3.10	..	24.43	32.78	..
14 . . . . .	3.8	2.96	..	27.19	30.70	..
15 . . . . .	3.1	3.06	..	26.42	28.81	..
16 . . . . .	3.9	3.46	..	25.72	28.27	..
17 . . . . .	3.9	3.49	..	28.64	29.29	..
18 . . . . .	4.2	3.58	..	24.99	28.64	..
19 . . . . .	2.8	2.63	..	28.95	31.94	..
20 . . . . .	4.3	3.97	..	26.53	24.05	..
21 . . . . .	2.9	3.66	..	25.46	29.64	..
22 . . . . .	5.3	3.68	..	20.77	30.77	17.70
23 . . . . .	3.4	3.41	..	28.35	29.37	..
24 . . . . .	3.1	2.30	..	26.82	28.46	..
25 . . . . .	..	4.25	3.81	..	31.60	30.20
26 . . . . .	..	4.82	3.55	..	31.35	20.00
27 . . . . .	..	4.83	4.46	..	30.22	26.13
28 . . . . .	..	5.00	4.80	..	27.56	25.14
29 . . . . .	..	4.29	4.14	..	17.85	17.26
30 . . . . .	..	3.48	2.84	..	22.52	24.14
31 . . . . .	..	4.26	4.18	..	21.50	20.11
32 . . . . .	..	3.63	3.87	..	20.03	17.99
33 . . . . .	..	3.93	4.26	..	19.44	16.98
34 . . . . .	..	2.97	2.90	..	23.97	26.01

PLATE I.





Large lower leaves of all the types of *Carlinaus tinctorius* Linn., showing the division of margin.

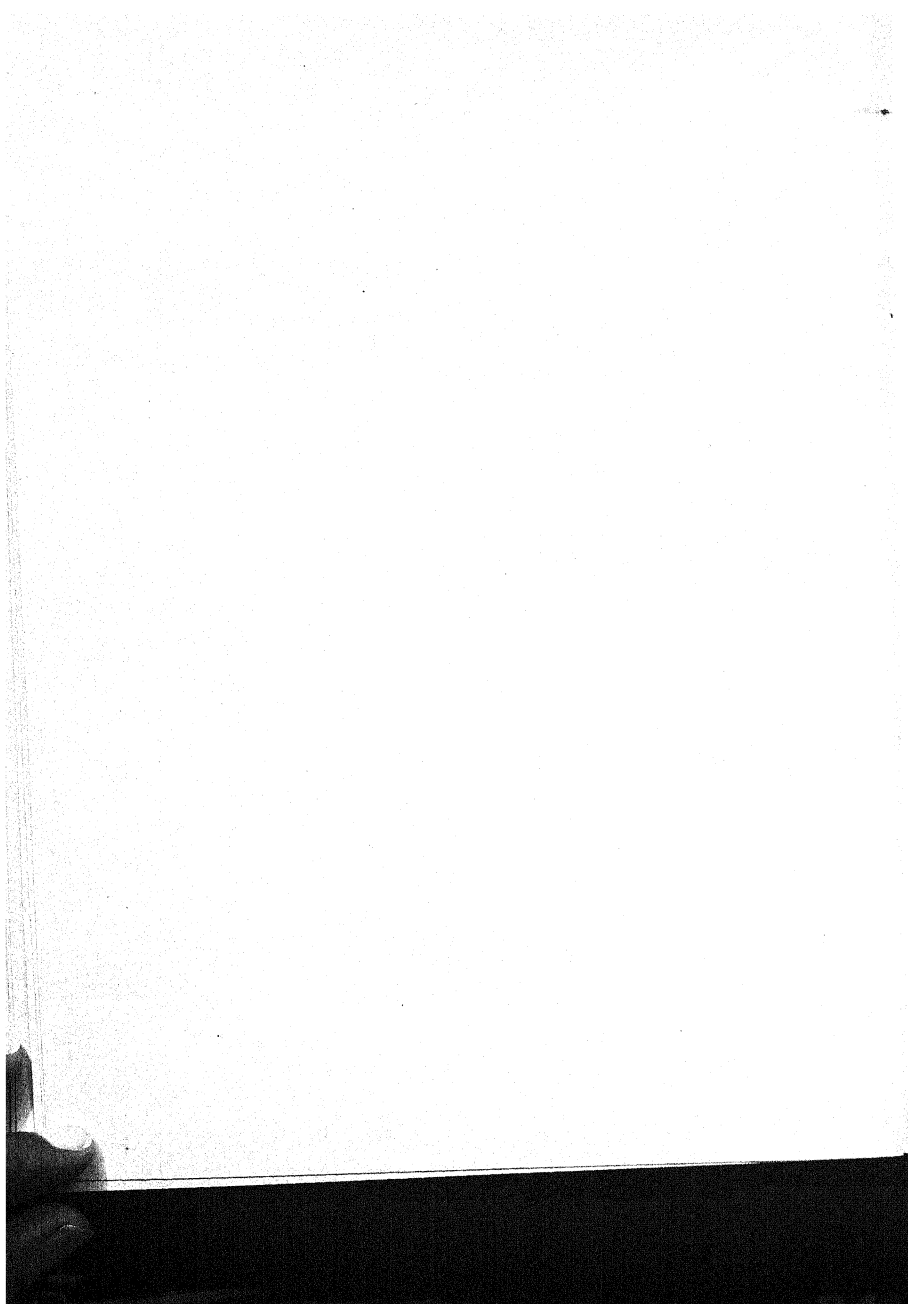


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## PREFACE.

The preparation of this Memoir has been delayed for a variety of reasons. It has been thought better, however, to keep to the original plan of recording results up to and including 1926-1927 and to publish further results in a second Memoir.

My acknowledgments are due to Dr. H. H. Mann, D.Sc. (now retired), who as Director of Agriculture planned, stimulated and controlled this research and who assisted me much in the drafting of the manuscript ; to Mr. M. L. Patel, M.Ag., Cotton Breeder, South Gujarat, Surat, for his help and criticism at all stages of the work ; and to Dr. W. Burns, D.Sc., Economic Botanist to the Government of Bombay, Poona, for help in the final drafting of the Memoir.

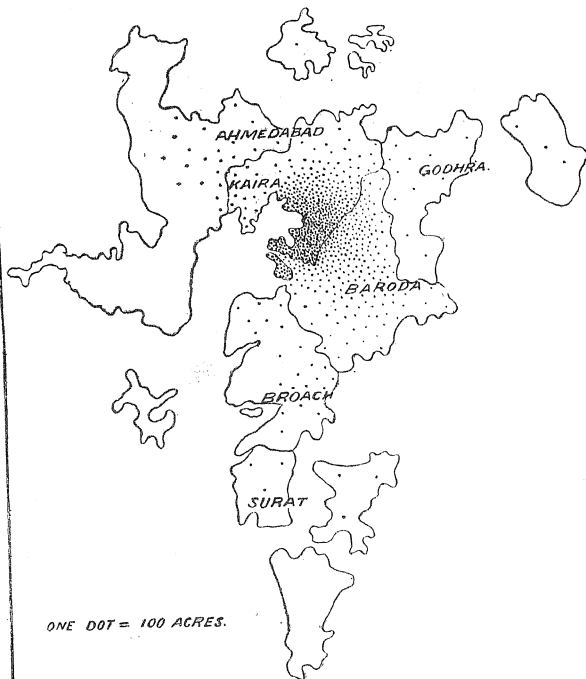
*Nadiad,*

*10th June, 1929.*

V. M. MAJMUDAR,

*Tobacco Breeder, Nadiad.*

MAP OF GUJARAT  
SHOWING AREA  
UNDER TOBACCO.



# STUDIES IN GUJARAT TOBACCOS AND THEIR IMPROVEMENT, PART I.

BY

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(Received for publication on 3rd August 1929.)

## I. INTRODUCTION.

The importance of the tobacco crop in India has been steadily increasing in recent years, and this has been obvious in Peninsular India, that is to say, in the Madras and Bombay Presidencies. In Madras, while, as recently as 1905-06, the area was a little over 130,000 acres, it had amounted to 232,000 acres in 1926-27. In Bombay, in 1905-06, the area was about 60,000 acres, but this had increased in 1917-18 to 93,000 acres, and in 1924-25 to 122,400 acres, though this latter acreage again fell to 101,000 acres in 1926-27.

But while, in the Bombay Presidency, the total area under tobacco cultivation has thus increased very considerably, yet the regions in which the crop is grown are the same as before. Almost the whole of the tobacco, in fact, is produced either in an area in the Western Deccan with Kolhapur as the centre but extending south into the Belgaum and north into the Satara Districts, or in a region centring round the Kaira District in Gujarat, and including portions of the Baroda State and of the Ahmedabad and Broach Districts. Each of these areas has its peculiarities, but the present study deals entirely with the tobacco grown in the second of them, *viz.*, that occurring in Upper Gujarat.

In Upper Gujarat, the importance of the crop has very rapidly increased. Thus, for instance, in the Kaira District itself, the present centre of cultivation, the tobacco crop occupied only three per cent. of the cropped area, in 1859-60 while in 1924-25 it occupied 5·7 per cent. and the actual acreage at various times has been recorded as follows:—

	Acres.
1859-60 . . . . .	10,827
1876-77 . . . . .	10,161
1903-04 . . . . .	15,577
1923-24 . . . . .	33,790
1924-25 . . . . .	47,304
1926-27 . . . . .	34,032

This large increase has been caused partly by the partial failure of water in the wells of the district, leading to the replacement of crops like sugarcane which require a large amount of irrigation water by those which require much less, like tobacco, and yet which give a fairly large monetary return per acre. It has also been connected with the very high reputation possessed by Gujarat tobacco for country consumption, for while other districts like the east coast of India and particularly Guntur have concentrated on growing cigarette tobacco, the growers in Gujarat have entirely, or almost entirely, devoted their attention to growing the strong, rank, thick tobacco which is most highly appreciated for *bidis* and other forms of country

consumption. The main market, in fact, for Gujarat tobacco is in the home smoking and in Central India. The work recorded in the present memoir has been primarily for the production of an improved type for this market, which, as will be seen, requires a tobacco of very different character from that needed for the foreign market or even for the local cigarette market.

## II. VARIETIES OF TOBACCO IN CULTIVATION IN GUJARAT.

There are records, albeit meagre, of the types of tobacco in cultivation in Gujarat at intervals since 1879. In the year mentioned,<sup>1</sup> there appear to have been two recognized types in cultivation, known as the "Talabdi" or local, and the "Khandeshi", which had been, at least traditionally, brought from Khandesh. The former, says the Bombay Gazetteer, was a tall plant with large juicy and tapering leaves, with heavy coarse veins, a loose texture, and a dull yellow colour when ripe. This was considered to be hardy, growing in poor soils, and needing little manure. The latter or Khandeshi type was a shorter plant, with short narrow leaves, with a closer texture than the local variety, and which produced a product with a deeper and more brilliant colour. The plants of this variety were considered more delicate, needing a richer soil and more manure, but less water.

Of these two types, the former corresponds fairly closely to the most common tobacco now grown, known as *Gandhi*; the latter is not widely dissimilar from that known as *Piliu*. The names found in 1879 are now quite unknown.

In 1901, Mollison<sup>2</sup> described the varieties then grown as follows:—

*Shanru*, plant with a very low habit of growth, internodes very close. Leaf very granulated or crumpled, broad with the greatest width one-quarter of the length from the base, gradually tapering to a moderately blunt point. The midrib, veins, and reticulations all prominent and coarse. Texture, thick, coarse, and soft.

*Peebia* plant fairly tall. Leaf granulated, large, widest about one-third of the length from the base, narrow for a very short distance from base, and then widening abruptly. The leaf tapers to a sharp point. The midrib, veins, and reticulations all prominent and coarse. Texture, thick and soft.

*Kalia (Baroda) I.* Plant tall or moderately tall, leaves somewhat granulated, narrow for a short distance from the base, then widening and becoming widest about one-third of the length from the base. They are moderately broad, long, and sharp-pointed. The midrib and veins fairly coarse, the veins and reticulations numerous. Texture, fairly thick and soft.

*Kalia (Baroda) II.* Plant fairly tall, leaves crumpled or very much granulated, narrow for a short distance from the base and then widening abruptly, and becoming widest at one-fifth of the length from the base, then tapering gradually to a sharp point. The midrib, veins, and reticulation, long, prominent, and coarse. Texture, thick, coarse and soft.

<sup>1</sup> Bombay Gazetteer (Kaira District), 1879.

<sup>2</sup> Mollison. *Textbook of Agriculture*, Vol. III (Bombay, 1901).

*Unnamed variety from Nadiad.* Plant dwarf and low set. Leaves very crumpled, short and very wide in proportion to length, being widest one-third length from the base and thence tapering slowly to a sharp point.

A good deal of change has taken place in the types grown and in the names given to them since the above description was given by Mollison, but the varieties at present cultivated which correspond most closely are as follows :—*Shamru* corresponds fairly closely to *Gandiu* as now grown. The name *Shamru* is no longer used. *Peelia* is similar to the present day *Piliu*. *Kaia* is now known as *Keliu*, and the two types described under this name by Mollison cannot be distinguished. The Nadiad unnamed variety cannot now be identified.

At present, all the cultivated tobaccos of Northern Gujarat belong to the species *Nicotiana Tabacum*. *Nicotiana rustica* is rarely found even in gardens. The predominant variety, not only in the Kaira District but throughout the Bombay Presidency, is that known locally as *Gandiu*, and this, according to Howard's <sup>1</sup> classification, belongs to his class II B, i.e., those with broad and elliptical leaves tapering at both ends. These types have a leaf ratio between 2 and 3. Though this *Gandiu* is the predominant type everywhere in Western India, the variation in the local varieties is far greater in the Kaira and adjoining districts than in other parts of the Bombay Presidency.

It is proposed, therefore, to give a description of the average type, as now grown, of each of the recognized varieties in this area, and indicate the variations which have shown themselves in the characters during the five years this study has been in hand. It will, of course, be quite obvious that the individual variations are very great, and the average type is not easy to recognize in any single plant, but it seems wise to place on record a note of these characters and their seasonal variations when grown under identical conditions at Nadiad.

The varieties now grown are as follows :—

*Gandiu*. This variety, as already stated, is far the most important and generally grown, both in the irrigated and in the dry tobacco area. It occupies at least fifty per cent. of the area under the crop. It has a large, broad, coarse, thick leaf, giving a "strong" tobacco. It is the least tall of all the varieties grown, and has the compact, short, and almost flattened inflorescences which are also found in *Keliu* and *Movadiu*. The capsules are wider than those of *Piliu* and *Shengiu*.

*Piliu*. This variety is particularly grown at Petlad (Baroda) and in parts of Borsad and Anand Talukas (Kaira). In the Kaira District and adjoining parts, it occupies about half the area which is grown with *Gandiu*. It has a narrower and shorter leaf than the latter, being particularly narrow at the base, and almost, at first sight appears to have a petiole. It is usually considered to give a higher quality of tobacco than *Gandiu* being superior in colour and strength. The plant is taller than *Gandiu* and has long inflorescences with flowers sparsely arranged.

<sup>1</sup> Howards, A. and G. L. C. Studies in Indian Tobaccos. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. III, No. 2.

It ripens about three weeks earlier than the *Gandiu* variety. The capsules are narrower and smaller than those of *Gandiu*.

*Keliu*. This variety is found most largely in the Borsad and Anand Talukas (Kaira), while it is also grown in the adjoining parts of the Baroda State. It occupies nearly the same area as the *Piliu* variety and is a late type. It is grown both in the irrigated and in the dry tobacco area. It has the largest leaves of any of the varieties grown. It is the tallest amongst the local type and has long internodes. As it prefers somewhat brackish water, it is a favourite variety of Dharmaj (Baroda) and Virsad (Kaira) villages where there are wells known for their brackish water. The produce of this type when grown under these wells is largely used for hookah tobacco and for snuff.

*Mowadiu*. This variety is grown only on a very small scale and generally as a dry crop, almost entirely in the Thasra Taluka (Kaira). It takes its name from the resemblance of its leaf to that of *Mowra* tree (*Bassia latifolia*). It has very dark green leaves in the early stages of growth with very prominent veins. In shape the leaf resembles *Gandiu*, the breadth being very great.

*Shengiu*. This variety is also only grown on a small scale and generally as a dry crop, only in the Thasra Taluka (Kaira). The leaf is the longest of all the types, and has long narrow portion at the base almost looking like petiole. The leaf is thin and hence it is considered poor in quality, thus commanding a low price.

The varieties described above have been grown at Nadiad under identical conditions since 1922-23, and measurements have been taken of a large number of plants (exact number of cases given in respective tables) of each variety in each season. The average of these measurements in each year and the general average for the years included may now be given.

(A) Height of the plants.

TABLE I.

Height of the tobacco plant from base to the top of the main axis.

Variety	YEARS.					
	1922-23	1923-24	1924-25	1925-26	1926-27	Average
	Mean c <sup>2</sup>	Mean c	Mean c	Mean c	Mean c	Mean c
	cm.	cm.	cm.	cm.	cm.	cm.
1. <i>Gandiu</i>	76.4 2.2	64.0 1.1	79.3 0.6	74.2 1.4	80.9 1.3	76.5 1.3
2. <i>Piliu</i>	79.7 2.0	76.7 1.1	103.5 0.3	65.1 0.8	105.0 1.7	81.0 0.6
3. <i>Keliu</i>	96.2 3.9	.. ..	.. ..	115.0 3.6	132.9 2.9	115.3 2.4
4. <i>Mowadiu</i>	101.0 2.8	35.8 1.6	115.3 1.0	96.1 1.0	94.3 1.6	105.0 1.4
5. <i>Shengiu</i>	92.6 2.4	76.3 1.7	105.5 1.4	70.7 0.9	81.3 1.6	84.3 1.0

It will be seen that the *Keliu* is the tallest with *Mowadiu* next. *Keliu* and *Shengiu* are the most variable on the whole and *Gandiu* is the least variable.

$$^{\circ}\text{Standard Error of the Mean} = \frac{s}{\sqrt{n}}$$

## (E) Length and greatest breadth of leaf and leaf ratio.

TABLE II.

Length of the tobacco leaf of different varieties.

Variety	YEARS					
	1922-23	1923-24	1924-25	1925-26	1926-27	Average
	Mean $\pm$	Mean $\pm$	Mean $\pm$	Mean $\pm$	Mean $\pm$	Mean $\pm$
	cm.	cm.	cm.	cm.	cm.	cm.
No. of cases 100 to 200						
1. <i>Gandia</i>	26.0 -58	44.5 -34	47.0 -19	41.2 -19	32.7 -58	43.1 -17
2. <i>Pilia</i>	32.0 -40	35.3 -36	40.6 -25	32.1 -24	31.8 -40	36.6 -19
3. <i>Kelia</i>	37.0 -55	.. ..	.. ..	43.7 -85	35.2 -40	38.3 -40
4. <i>Muradiah</i>	34.0 -44	41.5 -48	37.0 -29	40.5 -22	35.5 -57	37.4 -16
5. <i>Shengia</i>	43.0 -71	44.7 -61	48.0 -34	37.0 -39	34.0 -67	43.2 -29

It will be seen that *Gandia* and *Shengia* are both long leaved with *Shengia* more variable, while *Pilia* is short leaved.

TABLE III.

Greatest breadth of the tobacco leaf of different varieties.

Variety	YEARS					
	1922-23	1923-24	1924-25	1925-26	1926-27	Average
	Mean $\pm$	Mean $\pm$	Mean $\pm$	Mean $\pm$	Mean $\pm$	Mean $\pm$
	cm.	cm.	cm.	cm.	cm.	cm.
No. of cases 100 to 200						
1. <i>Gandia</i>	15 -26	23 -21	24 -21	19 -34	16 -25	21.5 -26
2. <i>Pilia</i>	11 -20	15 -15	17 -15	12 -12	14 -20	14.6 -15
3. <i>Kelia</i>	16 -27	.. ..	.. ..	21 -26	16 -22	17.4 -24
4. <i>Muradiah</i>	13 -28	23 -24	20 -22	22 -28	15 -29	20.7 -26
5. <i>Shengia</i>	13 -32	17 -18	19 -19	13 -14	13 -24	15.2 -19

TABLE IV.

*Leaf ratio of tobacco leaves of different varieties.*

Variety	YEARS					
	1922-23	1923-24	1924-25	1925-26	1926-27	Average
	Mean $\sigma$	Mean $\sigma$	Mean $\sigma$	Mean $\sigma$	Mean $\sigma$	Mean $\sigma$
No. of cases 100 to 200						
1. <i>Gandiu</i> . . .	2.3 .002	1.8 .007	1.9 .005	2.1 .009	2.0 .018	2.0 .006
2. <i>Piliu</i> . . .	2.7 .002	2.3 .016	2.3 .015	2.7 .016	2.3 .022	2.5 .013
3. <i>Keliu</i> . . .	2.2 .002	.. ..	.. ..	2.1 .014	2.2 .013	2.2 .013
4. <i>Movadiu</i> . . .	1.9 .002	1.8 .016	1.8 .008	1.8 .008	2.4 .041	1.8 .006
5. <i>Shengiu</i> . . .	3.2 .004	3.5 .002	2.5 .001	2.9 .025	2.6 .066	2.8 .018

From the above Tables, it will be seen that these tobaccos range themselves into two groups; one of these, composed of the narrower leaved varieties, includes *Piliu* and *Shengiu* with a leaf-ratio always over 2.3, while in certain seasons it may be much higher with a general average of 2.5 or over. *Gandiu* and *Movadiu* varieties are broad, centering round 2.0, while *Keliu* is intermediate with an average leaf ratio of 2.2.

The size of the leaves depends, however, not only on the length and the breadth, but also on the position of the widest portion of the leaf and hence direct determination of the average size of 100 leaves was made by the Planimeter in 1926-27 with results as follows :—

Variety	Average size of leaves grown for seed in sq. cm.	
	Mean	$\sigma$
1. <i>Gandiu</i> . . . . .	369	12.3
2. <i>Piliu</i> . . . . .	291	8.1
3. <i>Keliu</i> . . . . .	326	9.6
4. <i>Movadiu</i> . . . . .	355	8.3
5. <i>Shengiu</i> . . . . .	279	7.1

The separation of *Piliu* and *Shengiu* varieties from the other Kaira tobaccos is still clearer.

## (C) Number of leaves per plant.

TABLE V.

Total number of tobacco leaves borne by the plant from base to inflorescence.

Variety	YEARS				
	1923-24	1924-25	1925-26	1926-27	Average
	Mean $\bar{x}$	Mean $\bar{x}$	Mean $\bar{x}$	Mean $\bar{x}$	Mean $\bar{x}$
No. of cases 100 to 200					
1. <i>Gandhi</i> . . . . .	33.9 .17	30.7 .13	33.0 .00	39.1 .41	32.3 .09
2. <i>Piliu</i> . . . . .	29.8 .22	27.1 .13	28.1 .18	37.3 .55	29.2 .12
3. <i>Keliiu</i> . . . . .	. . . . .	40.9 .62	45.1 .38	43.0 .68	
4. <i>Moradiu</i> . . . . .	35.0 .21	35.3 .10	37.0 .12	38.2 .30	36.2 .08
5. <i>Shengiu</i> . . . . .	28.3 .38	27.3 .23	28.1 .19	36.2 .58	29.1 .22

It will be seen that, so far the variation in the number of leaves from season to season is concerned, the differences are considerable. They are, in fact, almost as great as in the extreme cases among the types isolated by Howard.<sup>1</sup> The very high figures found for *Keliiu* and *Moradiu* tobaccos have not been observed elsewhere in India. The number of leaves in 1926-27 was high, but the relative positions of the varieties are almost the same as for all the years taken together.

## (D) Period required for blooming.

The inflorescence in *Gandiu*, *Keliiu* and *Moradiu* tobaccos is compact and short, being almost flattened on the top, the side branches being usually level with the main axis. In the *Piliu* and *Shengiu* varieties, on the other hand, the inflorescence is long and the flowers are sparsely arranged.

The tobacco is transplanted about the 3rd or 4th week in August, and the period required for blooming is calculated from this date to the date of opening of the first flowers on each plant. The figures actually recorded are as follows :—

TABLE VI.

Period required for blooming.

Variety	YEARS				
	1923-24	1924-25	1925-26	1926-27	Average
	Days	Days	Days	Days	Days
	Mean $\bar{x}$	Mean $\bar{x}$	Mean $\bar{x}$	Mean $\bar{x}$	Mean $\bar{x}$
<i>Gandiu</i> . . . . .	79 0.6	68 0.6	89 1.3	97 1.7	81 0.6
<i>Piliu</i> . . . . .	77 1.4	52 0.4	71 0.4	73 1.7	68 0.6
<i>Keliiu</i> . . . . .	. . . . .	. . . . .	90 2.6	132 1.9	123 2.1
<i>Moradiu</i> . . . . .	86 1.1	91 0.9	92 0.7	108 1.1	92 0.5
<i>Shengiu</i> . . . . .	66 2.1	49 0.6	73 1.3	68 2.0	64 0.9

<sup>1</sup> Howard, G. L. C. The Inheritance of Characters in *Nicotiana Tabacum*. Mem. Dept. Agri. India, Bot. Ser., Vol. VI, No. 3 (1913).

Thus *Piliu* and *Shengiu* are early varieties, *Keliu* and *Movadiu* are late types and *Gandiu* is intermediate. It will be seen that there are very considerable fluctuations as to the average length of the period required for blooming in different years, and that all the varieties are not affected in the same way in each year.

### III. CONDITIONS OF TOBACCO GROWING IN UPPER GUJARAT.

Tobacco growing in Upper Gujarat is done on somewhat light soil, either of the class known as *gorudu*, which is really an old alluvial silt, on newer alluvium above flood level, or in a few cases even in river-beds. Both the *gorudu* soils and the newer alluvium are of great depth, usually of fine consistency, varying however in character from a sandy loam to a moderately stiff clay loam. Where there are stiff patches either on the surface or in the sub-soil through which the roots of tobacco plants find it difficult to penetrate, there the tobacco is inferior.<sup>1</sup> Such patches can, it has been shown, be made to grow excellent tobacco by aeration of the soil by means of drains and application of large doses of farmyard manure.

The soil of the Nadiad Research Station, which is typical of the tobacco growing tract, gave the following figures on analysis in 1926<sup>2</sup> :—

	Per cent.
Total nitrogen . . . . .	0.082
„ phosphoric acid . . . . .	0.2122
„ potash . . . . .	0.456
„ lime . . . . .	1.356
„ available phosphoric acid . . . . .	0.1318
Available potash . . . . .	0.0657

**Rainfall.** The average annual rainfall<sup>3</sup> at Nadiad, which lies in the centre of the area, for forty-eight years is 33.60 inches. The variability in the total rainfall is indicated by the fact that in six years (out of 48) there has been less than 14 inches, in one year the fall was between 14 and 21 inches, in seven cases the amount lay between 21 and 28 inches, in sixteen years the quantity was between 28 and 35 inches, while in eighteen years it was over 35 inches.

The monsoon begins by about the end of June, and the heaviest rainfall is in July; it closes by the end of September and, in October, rain is absent or very scanty. The average fall for each of these months has been as follows :—

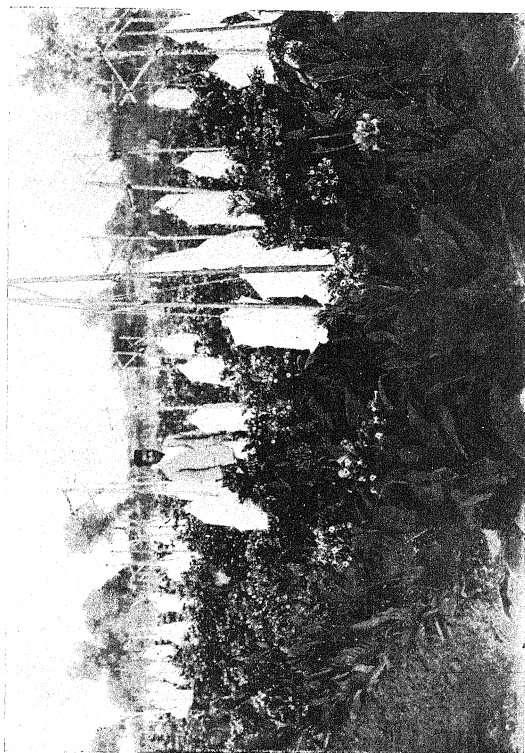
	Inches.
June . . . . .	4.43
July . . . . .	12.69
August . . . . .	10.53
September . . . . .	5.11
October . . . . .	0.44
November . . . . .	0.25

<sup>1</sup> Mann, Patel and Majmudar. The Treatment of Patches of Inferior Tobacco in North Gujarat. *Bom. Dept. Agri. Bulletin* No. 129 of 1926.

<sup>2</sup> This analysis was kindly done by the Imperial Agricultural Chemist, Pusa.

<sup>3</sup> The figures of rainfall for 1876 to 1915 are taken from the record supplied by the Executive Engineer, Gujarat Irrigation District, and for 1916 onwards from the records of the Government Farm, Nadiad.

PLATE II.



TOBACCO RESEARCH STATION, NADIAD.



*Temperatures.* The following shows for each month of the year at Nadiad the average maximum and the average minimum shade temperatures during the last ten years :—

Month	Average maximum shade temperature F°	Average minimum shade temperature F°
January . . . . .	82	52
February . . . . .	86	53
March . . . . .	94	63
April . . . . .	93	60
May . . . . .	100	75
June . . . . .	95	78
July . . . . .	85	75
August . . . . .	85	73
September . . . . .	86	72
October . . . . .	90	67
November . . . . .	88	58
December . . . . .	84	53

*Cultivation.* In the area now under discussion tobacco is rarely rotated with other crops. It is believed by the people that the longer the soil is under the crop, the better is the produce. Seedbeds are usually made on high level land, and under the shade of trees. If the necessity of such land is not realized, and the seedlings are grown in the ordinary fields, there is often a large loss, if storms occur. Thinning of seedbeds is not commonly carried out, and hence the seedlings used for transplanting are often weak. The seedbeds are manured with farmyard manure, or with goat manure. 100 square feet of seedbed is usually considered enough to plant out an acre, and one ounce of tobacco seed is sufficient for this area.

The land in which the tobacco is ultimately to grow is ploughed five to seven times with the local plough, after the monsoon starts. Farmyard manure is given at the first ploughing at the rate of ten tons per acre. After the last ploughing, the soil is compressed with a flat plank to ensure a firm bed. Seedlings are generally planted two feet apart in both directions, though there is a tendency now-a-days to increase this distance to two and a half feet. In the case of the *Piliu* variety the seedlings are planted closer, namely about 18 inches apart.

Seedlings are usually transplanted when they have four leaves, in the second half of August. If the crop is to be raised without irrigation, it is planted earlier by about a fortnight. The land is hoed seven or eight times after transplanting, the first two hoeings being done by hand. Three or four waterings are usually given to irrigated tobacco, at intervals of a fortnight. The first irrigation is delayed as long as possible. The *Kelii* tobacco grown in the Borsad Taluka is watered with brackish water often containing a distinct proportion of nitrates, and the yield is consequently very high, being about 2,200 to 2,600 pounds of cured tobacco per acre.

When the flowering shoot appears, it is nipped off, leaving usually 14 to 16 leaves on each plant, of which the lower four generally wither and die. Suckers forming in the axils of the leaves are removed regularly every week. The plants are ready for harvest between January and March, the time varying with the variety (See above).

#### IV. THE HEREDITY OF CERTAIN CHARACTERS IN GUJARAT TOBACCOS AND THEIR VARIATION.

The heredity of many characters in cultivated tobacco has been exhaustively examined in a series of Memoirs by Howards<sup>1</sup> and precautions necessary in such studies have been laid down by them. These special precautions, including the raising of seedlings in large boxes, manuring with well decayed farmyard manure purchased from a cultivator who does not grow tobacco, and the like, were taken. The seed-boxes were watered a month before sowing in order to secure the germination of any stray seed in the soil. They were sown one at a time and the sower was made to wash his hands before sowing another box.

The method of work in the present study has been to take the number of selections from existing types in the field, and grow them, self-fertilized, in a series of years. The criterion for judging the hereditary nature of any feature of a strain, is the constant relationship of the character in two or more strains in successive years. This study has been undertaken in the case of following characters :—

- (1) The length, and greatest breadth of the leaves and the leaf-ratio in plants grown for seed.
- (2) The length, and greatest breadth of the leaves and the leaf-ratio in plants grown for leaf.
- (3) The number of leaves per plant.
- (4) The number of veins in a leaf.
- (5) The thickness of the leaf.
- (6) The height of the plant.
- (7) The number and size of suckers ; and their time of appearance.
- (8) The period required for flowering.
- (9) The character of the inflorescence.

<sup>1</sup> Howards, A. & G. L. C. Studies in Indian Tobaccos. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. III, No. 1, 1910.

For this study, eight strains of tobacco, to all appearances breeding true in the characters studied, were taken. Three of these were of the *Gandiu* variety (Nos. 1, 4 and 6), two of the *Moradiu* type (Nos. 19 and 20), two represented *Piliu* tobacco (Nos. 28 and 30) and one was of *Shengiu* variety (No. 22). Selfed seed was used from year to year.

1. *The length and breadth of the leaves and leaf ratio in plants grown for seed.*

Following the methods used by the Howards, these characters have been studied by noting the absolute length and greatest breadth of a representative leaf <sup>1</sup> in the middle of the plants, and working out the leaf ratio for each plant by dividing the length by the breadth. The measurements were taken after the inflorescence had appeared and a few capsules were formed. The number of cases recorded are given in each Table.

TABLE VII.

*Length of leaf in various tobacco strains grown for seed.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	c	Mean	c	Mean	c	Mean	c
No. of cases	cm.		cm.		cm.		cm.	
	100 to 150		100 to 300		100 to 300		300 to 800	
1 . . .	49.6	.57	40.9	.53	34.3	.50	42.3	.53
4 . . .	46.6	.32	39.4	.26	35.3	.24	40.9	.23
6 . . .	45.6	.35	42.7	.26	37.4	.25	42.1	.21
19 . . .	40.7	.29	41.0	.27	34.0	.25	38.6	.21
20 . . .	33.8	.32	40.1	.35	31.6	.21	34.3	.22
22 . . .	47.9	.34	37.3	.39	36.8	.38	42.1	.33
28 . . .	46.4	.23	40.4	.23	33.3	.23	40.6	.22
30 . . .	40.6	.25	32.1	.24	29.9	.19	33.4	.32

<sup>1</sup>Howard's Studies in Indian Tobaccos. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. VI, No. 3, p. 80 (1913).

TABLE VIII.

*Greatest breadth of leaf in various tobacco strains grown for seed.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$
No. of cases	cm.		cm.		cm.		cm.	
	100 to 150		100 to 300		100 to 300		300 to 800	
1 . . .	24.2	.21	18.6	.34	16.2	.28	21.0	.26
4 . . .	24.5	.16	20.1	.15	17.6	.13	21.0	.15
6 . . .	23.3	.22	19.1	.15	17.8	.15	20.1	.15
19 . . .	20.8	.15	21.2	.18	16.8	.12	19.9	.13
20 . . .	19.6	.22	23.3	.30	17.2	.12	19.6	.15
22 . . .	19.5	.19	13.6	.15	12.8	.15	15.8	.19
28 . . .	23.3	.16	17.9	.13	15.1	.11	18.8	.15
30 . . .	17.1	.15	11.8	.12	11.4	.11	13.4	.13

TABLE IX.

*Leaf ratio in various tobacco strains grown for seed.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$
1 . . .	1.96	.014	2.20	.018	2.19	.017	2.10	.013
4 . . .	1.86	.007	1.93	.010	1.95	.004	1.89	.006
6 . . .	1.93	.008	2.27	.009	2.08	.006	2.00	.006
19 . . .	1.94	.006	1.94	.007	1.99	.004	1.95	.004
20 . . .	1.70	.009	1.69	.007	1.83	.005	1.74	.005
22 . . .	2.47	.014	2.88	.025	2.85	.009	2.65	.013
28 . . .	1.98	.009	2.26	.009	2.09	.006	2.16	.007
30 . . .	2.35	.015	2.70	.016	2.62	.010	2.56	.010

In connection with these figures, it is interesting to see the actual average area of the leaf in each case of the above strains as measured by the planimeter in 1926-1927. This was as follows :—

Strain No.										Leaf area in sq. cm.	
										Mean	ε
1	.	.	.	.	.	.	.	.	.	371	12.1
4	.	.	.	.	.	.	.	.	.	388	5.7
6	.	.	.	.	.	.	.	.	.	424	6.8
19	.	.	.	.	.	.	.	.	.	352	5.7
20	.	.	.	.	.	.	.	.	.	351	4.1
22	.	.	.	.	.	.	.	.	.	288	6.7
28	.	.	.	.	.	.	.	.	.	335	4.7
30	.	.	.	.	.	.	.	.	.	228	3.7

The biggest leaf is in No. 6 and the smallest leaf in *Piliu* No. 30.

## 2. Length and greatest breadth of leaves and the leaf ratio in plants grown for leaf.

Similar tests, to those just described, were made with plants topped and from which the suckers were regularly removed, while the measurements were taken, a few days before harvest, on the third leaf of each plant from the top. The actual figures are as under :—

TABLE X.

*Length of the leaf in various tobacco strains grown for leaf.*

Strain No.		1924-25		1925-26		1926-27		Average	
		Mean	ε	Mean	ε	Mean	ε	Mean	ε
		cm.		cm.		cm.		cm.	
No. of cases		100 to 200		100 to 400		100 to 300		300 to 800	
1	.	41.2	.62	43.6	.57	41.9	.45	42.7	.28
4	.	39.0	.25	40.9	.34	35.8	.31	38.5	.18
6	.	40.9	.26	45.0	.29	39.5	.32	42.6	.18
19	.	40.5	.34	40.6	.30	36.8	.28	39.8	.18
20	.	36.6	.28	38.5	.34	35.1	.25	36.6	.18
22	.	45.5	.45	40.4	.34	39.6	.32	41.7	.24
28	.	43.4	.25	39.0	.24	38.0	.24	40.4	.16
30	.	41.2	.24	34.3	.21	33.3	.19	36.9	.17

TABLE XI.

*Greatest breadth of the leaf in various tobacco strains grown for leaf.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	$\epsilon$	Mean	$\epsilon$	Mean	$\epsilon$	Mean	$\epsilon$
No. of cases	cm.		cm.		cm.		cm.	
	100 to 200		100 to 400		100 to 300		300 to 800	
1 . . .	20.8	.27	21.6	.36	20.0	.22	21.0	.23
4 . . .	21.2	.31	23.6	.24	20.2	.19	22.1	.16
6 . . .	20.9	.29	22.7	.19	18.5	.10	21.4	.15
19 . . .	22.7	.24	23.4	.21	19.4	.12	22.0	.16
20 . . .	22.8	.38	23.8	.26	19.2	.16	22.3	.17
22 . . .	18.4	.37	14.1	.12	13.4	.15	14.4	.12
28 . . .	22.0	.29	17.8	.15	17.4	.16	18.4	.12
30 . . .	17.8	.27	12.8	.09	13.1	.11	13.9	.11

TABLE XII.

*Leaf ratio in various tobacco strains grown for leaf.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	$\epsilon$	Mean	$\epsilon$	Mean	$\epsilon$	Mean	$\epsilon$
1 . . .	2.05	.018	2.10	.013	2.20	.022	2.05	.012
4 . . .	1.85	.016	1.79	.007	1.78	.008	1.82	.006
6 . . .	1.99	.017	2.03	.003	2.12	.011	2.07	.005
19 . . .	1.90	.012	1.84	.010	1.91	.010	1.88	.005
20 . . .	1.54	.020	1.66	.008	1.76	.008	1.72	.005
22 . . .	2.44	.030	2.91	.012	2.95	.016	2.88	.013
28 . . .	1.97	.014	2.26	.007	2.19	.011	2.19	.007
30 . . .	2.25	.027	2.71	.008	2.54	.011	2.61	.010

In connection with these figures, it is interesting to see the actual average area of the leaf in each of the above strains as measured by the planimeter in 1926-27. This was as follows :—

Strain No.	Average leaf area in sq. cm.	
	Mean.	$\sigma$
1 . . . . .	511	12.2
4 . . . . .	468	8.3
6 . . . . .	468	9.3
19 . . . . .	448	6.8
20 . . . . .	439	6.8
22 . . . . .	313	5.6
28 . . . . .	423	6.5
30 . . . . .	281	4.2

The biggest area is not in No. 6 in this section as is the case in the seed section. *Piliu* No. 30 has the smallest leaves. It will be seen generally from these figures that the leaves are smaller in 1926-27 than in the two previous years. In spite of these seasonal variations, the long-leaved types Nos. 1, 6, 22 and 4 have maintained their positions, while the short leaved-type No. 30 has remained the shortest throughout. It will be seen that the leaf ratio is more constant. The strain No. 20 has a low figure in each year, while No. 30 and No. 22 have a high leaf-ratio throughout. The constancy of this relationship indicates the hereditary nature of the leaf shape.

By comparing these results with those from plants grown for seed, it will be seen that the relative positions of the varieties are not the same. In the plants grown for leaf, strain No. 1 had the largest leaf, while it stood third in the series when grown for seed. The types with lowest area (Nos. 30 and 22) are, however, the same in both the cases. The effect of topping and removing suckers on the size of the leaf varies considerably in different strains, the greatest result being shown in No. 1 and the least in Nos. 6 and 22.

### 3. The number of leaves per plant.

The total number of leaves on the main stem was noted after the capsules were ripe, by counting from the basal leaf scar to the tip of the axis where the last leaf below the inflorescence on the main stem occurs. The Howards<sup>1</sup> considered this

<sup>1</sup> loc. cit.

as a definitely heritable character, though the variation between the individuals in a pure type is large in comparison with the variation between the types. They say that though the height varies greatly with season, the average number of leaves remains constant. In the investigations here recorded, however, where types occur with a larger number of leaves than in any case they examined, it is found that the number varies widely from season to season, as well as very widely from strain to strain. This variation is particularly marked in types with a large number of leaves. In seasons where, owing to climatic conditions, the leaves are small, the number tends to be high; when the leaf size is great, the number is reduced.

TABLE XIII.

*Number of leaves in various tobacco strains grown for seed.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$
No. of cases	100 to 150		100 to 200		100 to 300		300 to 800	
1 . . .	27.0	.20	30.3	.28	32.6	.24	30.1	.20
4 . . .	36.4	.20	34.0	.14	38.1	.13	36.0	.12
6 . . .	30.8	.14	31.0	.15	33.2	.14	31.5	.08
19 . . .	34.0	.24	37.0	.15	39.6	.18	37.6	.13
20 . . .	35.7	.10	37.1	.18	42.1	.16	38.2	.14
22 . . .	27.3	.23	28.1	.19	36.0	.21	30.7	.26
28 . . .	28.6	.24	31.0	.14	37.1	.21	33.0	.18
30 . . .	27.1	.13	28.1	.18	37.9	.20	31.5	.21

It will be seen that the seasonal variation in some cases is great and may obscure the hereditary differences. The increase in number of leaves in the somewhat unfavourable season of 1926-27 has been very high in early types (Nos. 22, 28 and 30). It may be interesting to note the number of living leaves at the time of harvest, as the power to retain the lower leaves is a very important factor in yield. The Strain No. 6, which has proved itself a high yielder when grown

on a large scale, has this faculty highly developed. The recorded figures are as follows :—

TABLE XIV.

*Number of living leaves at harvest in various strains.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$
No. of cases	100 to 300		100 to 300		100 to 300		300 to 800	
1 . . .	13.4	.24	12.6	.21	13.5	.15	12.8	.11
4 . . .	11.5	.08	12.1	.13	12.7	.09	11.9	.06
6 . . .	11.8	.09	12.4	.10	14.4	.09	12.7	.06
19 . . .	10.4	.09	12.0	.10	12.5	.11	11.6	.07
20 . . .	12.0	.10	12.7	.15	11.9	.10	12.2	.07
22 . . .	10.3	.12	13.6	.16	12.5	.09	12.4	.09
28 . . .	10.7	.08	12.6	.09	12.0	.09	11.8	.06
30 . . .	9.9	.09	12.7	.09	10.9	.11	11.1	.07

It will be seen that the *Gandhi* types, as a whole, are able to retain the greatest number of living leaves. The types which are usually grown dry (Nos. 19 and 20) retain less leaves than the others even though irrigation is given and though they have the largest number of leaves produced when allowed to seed.

#### 4. *The number of veins in the leaf.*

The number and size of the veins in a leaf are of especial importance in connection with the growth of cigarette tobacco, where large veins and large number of them lower the value of the produce. On the other hand, it is of far less importance in the tobacco demanded locally and it is this latter demand for which these strains were selected. This character was noted by counting the number of the secondary veins arising from the mid-rib, on the right side of the representative leaf.

TABLE XV.  
Average number of veins per leaf in various tobacco strains.

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	c	Mean	c	Mean	c	Mean	c
No. of cases	150 to 300		150 to 300		150 to 300		400 to 600	
1 . . . .	13.0	.08	13.2	.08	12.1	.13	12.8	.07
4 . . . .	12.8	.06	12.2	.10	12.5	.06	12.4	.04
6 . . . .	11.9	.07	11.2	.07	11.9	.06	11.6	.04
19 . . . .	12.2	.06	12.7	.05	12.2	.05	12.4	.03
20 . . . .	11.3	.06	11.8	.06	11.4	.06	11.4	.03
22 . . . .	11.2	.06	10.3	.08	11.0	.06	10.9	.04
28 . . . .	9.4	.07	11.6	.07	10.5	.04	10.5	.05
30 . . . .	10.0	.05	9.8	.07	10.1	.05	10.0	.04

The number of veins in the leaf in each case is remarkably constant from year to year. The strains with many veins remain so throughout, and likewise those with a small number. The character is therefore clearly hereditary.

In Connecticut broad leaf tobacco,<sup>1</sup> it has been claimed that the large size of leaf is correlated with large veins and rather coarse and inferior basal portions of the leaf. This seems to be also the case in the present strains.

##### 5. The thickness of the leaves.

The author is not aware that this character has been studied by any previous worker on the subject, but in the present case, the matter seemed of importance. In fact, in the local market, the demand is for a "strong" tobacco with thick leaves. Hence the question as to whether thickness of the leaves is a hereditary character came to the front.

The thickness was determined, in cured leaves, by means of a micrometer screw, one square inch of the central part of the right side of the leaf being removed for the purpose of the determination. The portion was taken near the mid-rib so as not to include any of the secondary veins, and was placed between two thin iron plates of known thickness for measurements. All readings were taken in hundredths of a millimetre. This method is not suitable for green leaves, as they are too easily compressed and accurate reading is difficult. A microscopic method of measurement was also tried, but the sectioning of leaves, either green or cured, for the purpose was difficult as they are liable to crack. The figures obtained are given below:—

<sup>1</sup> Shamel and Cobey, Tobacco Breeding, 1907.

TABLE XVI.  
Average thickness of cured leaves of various strains.

Strain No.	1924-25	1925-26	1926-27	Average
	Mean c	Mean c	Mean c	Mean c
	$\frac{1}{100}$ mm.	$\frac{1}{100}$ mm.	$\frac{1}{100}$ mm.	$\frac{1}{100}$ mm.
No. of cases	100 to 150	100 to 200	100 to 200	300 to 600
1 . . .	8.8 .33	11.3 .30	10.2 .25	9.8 .22
4 . . .	9.0 .26	10.5 .20	8.2 .19	9.3 .13
6 . . .	8.9 .27	11.4 .17	8.4 .18	9.4 .12
19 . . .	7.8 .23	11.1 .18	6.7 .16	8.7 .15
20 . . .	6.7 .22	9.0 .16	6.1 .14	7.5 .13
22 . . .	6.5 .20	11.6 .21	9.4 .20	9.2 .16
28 . . .	8.0 .18	10.7 .18	10.5 .19	9.2 .11
30 . . .	8.0 .21	11.4 .18	9.6 .19	9.7 .12

These figures show that we are dealing with an extraordinarily variable character, as would perhaps be expected. It may generally be stated that the thick strains remain relatively thick, through the series of years, as in the case of numbers 1, 28 and 30, while No. 20 is thinnest throughout. No. 20 is recognized as the best for chewing on this account. The *Piliu* types (Nos. 28 and 30) are considered thick and valued accordingly by the local market. The case of No. 22 is peculiar; it was the thinnest in 1924-25, but was thick in the succeeding two years, thereby bringing the average nearly similar to that of the other thick types.

Thus, though there is strong evidence that the character is heritable, yet the very large variability in a single season as shown by the high standard error makes any conclusion somewhat uncertain. This large variation is due, of course, to environmental conditions.

#### 6. Height of the plants.

The height of the plants is measured from the point where the roots begin to the apex of the stem, which in *Nicotiana Tabacum* ends with a capsule at ripening. This character is important, as the tobacco growers do not like tall types, though some of the very short strains seem equally objectionable. The figures obtained with the pure strains are given in the Table.

TABLE XVII.

*Height of the plants.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean $\bar{x}$		Mean $\bar{x}$		Mean $\bar{x}$		Mean $\bar{x}$	
	cm.		cm.		cm.		cm.	
No. of cases	150 to 300		150 to 300		150 to 300		400 to 600	
1 . . .	73.3	1.30	65.0	1.02	72.7	1.03	70.4	.73
4 . . .	98.5	0.74	82.9	0.76	94.0	0.73	91.9	.68
6 . . .	70.3	0.71	69.4	0.69	76.8	0.58	71.7	.39
19 . . .	96.5	0.85	82.5	0.81	97.0	0.64	91.9	.71
20 . . .	132.4	0.95	111.8	1.19	131.4	1.00	126.2	.71
22 . . .	105.5	1.37	70.7	0.92	85.8	1.08	90.4	.99
28 . . .	118.8	1.05	81.7	0.75	91.6	1.00	96.6	.94
30 . . .	103.5	0.90	65.4	0.82	94.6	0.83	86.5	.74

The relative position of the strains is fairly well maintained and the character may be considered as definitely hereditary. The variation within each strain is not very high for such a vegetative character as that under discussion.

#### 7. *The number and size of suckers.*

The removal of suckers is one of the most laborious jobs in tobacco cultivation, more especially in India, where the local tobaccos produce them far more than is customary with the plant as grown in other countries. The production of suckers has been supposed to be correlated with other characters.<sup>1</sup> Shamel and Cobey state for the types examined in America that "the non-suckering plant has a large number of more rounded leaves than the suckering plant, which condition is usually true in all such cases. The production of many large suckers is usually correlated with the development of few, heavy, dark and usually narrow pointed leaves. \*\*\*\*\* The continued observations on this subject have confirmed the conclusions that there is a correlation between the number, shape, and character of the leaves borne by individual plants and the number and size of suckers produced by these plants".

<sup>1</sup>U. S. A. Department of Agriculture, Bureau of Plant Industry, Bull. No. 96 (1907).

All the Indian types grown in Gujarat have a few, heavy, living leaves and have also a large number of suckers. Foreign tobaccos tested in Gujarat have a much smaller number of suckers than the local types, but the suggested relationship of the number with the other leaf characters does not seem to apply in the present cases. The following table shows the number of suckers removed per plant during its growth, the removal taking place at intervals of 10 to 13 days during the whole season :—

TABLE XVIII.  
*Number of suckers per plant in various strains.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Mean	s	Mean	s	Mean	s	Mean	s
1 . . .	26.3	.94	21.9	.70	21.3	.57	23.6	.54
4 . . .	32.1	1.10	30.6	.92	47.6	.55	32.5	.45
6 . . .	22.2	1.10	21.8	.67	24.9	.57	22.8	.40
19 . . .	33.2	1.97	31.8	.83	37.9	.63	34.5	.53
20 . . .	28.0	0.97	27.3	1.07	36.0	.57	31.0	.52
22 . . .	25.0	0.71	23.9	0.95	37.0	.57	29.4	.62
28 . . .	26.0	0.76	25.4	1.11	37.3	.44	30.6	.45
30 . . .	16.7	0.60	22.9	0.71	24.9	.28	22.4	.31

It will at once be seen that this character is very variable as shown by the standard error. But in some seasons the number of suckers is much higher than in others, and it is interesting to note that in 1926-27, when sucker formation was particularly active, the leaves were the smallest in the series of years. But generally speaking, the types, producing many suckers like Nos. 4 and 19, retain this character throughout and those producing few, like Nos. 1, 6 and 30, also retain their position. Thus there is a strong evidence of the hereditary nature of the capacity and tendency to produce suckers and it may be noted that, in part, the popularity of Strain No. 6 is due to the few suckers it produces, and hence to the less labour needed for the crop.

The number and size of suckers are not the whole question in regard to them, the stage of the plant life when they are formed is also of importance, and a strain, where they do not commence to form till late, would have special value. There is very great difference in this matter as the following Table shows, where the percentage of the total removed up to certain stages of the growth is indicated.

TABLE XIX.

*Time of formation of suckers with various strains. Percentage of suckers removed.*

Strain No.	1924-25			1925-26			1926-27		
	Days from planting			Days from planting			Days from planting		
	Before			Before			Before		
	80	80 to 100	100 to 130	80	80 to 100	100 to 130	80	80 to 100	100 to 130
	%	%	%	%	%	%	%	%	%
1 . .	6	35	59	8	54	38	2	43	55
4 . .	12	39	49	35	27	38	10	34	56
6 . .	7	27	66	17	35	48	..	27	73
19 . .	34	39	27	44	21	35	12	34	54
20 .	..	34	66	23	22	55	13	30	57
22 . .	26	48	26	33	36	31	47	29	24
28 . .	27	53	20	42	30	28	45	31	24
30 . .	61	27	12	54	25	21	72	23	..
33 . .	..	..	..	22	30	48	14	35	51
34 . .	..	..	..	25	32	43	16	35	49

From these figures it will be seen that, in certain strains such as Nos. 6 and 20, suckers arise much later than in certain others, as for example No. 30 where sucker formation begins at a very early stage of growth. It seems probable that not only is the amount of sucker formation a hereditary quality, but also the time at which they are formed is a definite strain character.

#### 8. *The period required for flowering*

The period from planting to opening of the first flower on each plant was taken as the criterion of this character. All the plants were numbered and the strains

were examined daily in the morning, with results which are given in the following table :—

TABLE XX.

*Period from planting to flowering in various strains.*

Strain No.	1924-25		1925-26		1926-27		Average	
	Days		Days		Days		Days	
	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$	Mean	$\pm$
1 . . . .	67	1.0	92	2.1	107	2.2	89	0.8
4 . . . .	70	0.7	84	1.1	99	0.9	82	0.7
6 . . . .	68	0.6	90	0.9	98	0.8	88	0.7
19 . . . .	87	1.1	93	0.9	106	1.0	97	0.7
20 . . . .	94	1.2	91	1.0	110	0.8	97	0.7
22 . . . .	49	0.6	73	1.3	79	0.7	69	0.9
28 . . . .	52	0.5	68	1.0	86	1.0	68	0.8
30 . . . .	52	0.5	70	1.1	77	1.0	68	0.7

The seasonal differences in the time required for flowering are large but the types occupy very closely the same relative position. The *Shengiu* No. 22 and *Piliu* Nos. 28 and 30 strains are consistently early in flowering. *Movadiu* Nos. 19 and 20 types are late. The *Gandiu* Nos. 1, 4 and 6 strains are variable and in the case of No. 1 the lateness in 1926-27 is hardly consistent with its position in the previous years. With this exception, the relative position of the strains is very closely kept in spite of the seasonal variation, showing that the character is a hereditary one.

#### 9. Character of the inflorescence.

There are two distinct types of inflorescence among the Gujarat varieties. In the *Gandiu*, *Keliu*, and *Movadiu* types the inflorescence is compact, the side branches being usually level with the main axis. In the *Piliu* and *Shengiu* types, on the contrary, the inflorescence is long and the flowers are sparsely arranged. Among compact-headed varieties, there is some evidence of the taller types tending to have longer inflorescences than the shorter ones. This inflorescence character has proved to be constant from year to year.

Further, the colour of the petals of the flowers has proved to be constant from year to year. This colour was always noted within one week from the opening of the first flower, for it seems to vary even in a single plant, at different parts of the season. The actual colour, as noted in the strains under consideration, was as follows :—

Strain No.	Colour of flower petals.
1. <i>Gandiu</i> . . . . .	White.
4. <i>Do.</i> . . . .	Pink.
6. <i>Do.</i> . . . .	White.
19. <i>Movadiu</i> . . . . .	Pink.
20. <i>Do.</i> . . . .	Deep pink.
22. <i>Shengiu</i> . . . . .	Pink.
28. <i>Piliu</i> . . . . .	Light Pink.
30. <i>Piliu</i> . . . . .	Pink.

#### V. THE IDEAL TYPE OF TOBACCO PLANT FOR NORTH GUJARAT.

In the following discussion it must at once be stated that, in considering the question of the ideal type of tobacco for cultivation in North Gujarat, the demand for the local market has been solely in view. If the cigarette demand or the foreign demand was the main object, then a different series of characters would probably be wanted.

But in any case, the question of uniformity will always be of greatest importance, and the best results will only be obtained when a pure bred strain is used. Further, the yield must be high and not very variable from year to year.

#### *Seedling characters.*

During the seedling stage of the tobacco in the Kaira District, there is a great liability to heavy and continuous falls of rain. Under these circumstances, in spite of every care, there is generally a great mortality among seedlings. The types selected have been found to vary very largely in their susceptibility to these unfavourable conditions, and the ideal tobacco would be one in which the mortality at this stage is low. Unfortunately, the most generally useful among the selections now multiplied for wide cultivation (*Gandiu* No. 6) is rather weak in this respect.

The seedlings must stand transplanting well, which is not the case with some of the foreign types, (such as "white Burley"), which are, hence, not suitable for cultivation in Gujarat.

#### *Plant characters.*

1. *Height.* The tobacco growers of North Gujarat have a great prejudice against types which grow rapidly at the beginning, as it is said to give a lower quality of leaf. The slow early growth also makes interculture easy. A tall plant is not liked, and one of medium height will always be preferred.

2. *Production of suckers.* It is very important that the production of suckers should commence late, and that suckers should be few in number, as this materially affects the cost of growing. The difference between the plants in the same field, with the mixed crop usually grown is very great, and this is reflected in the pure selections made in the course of the present work. In the favourite type *Gandiu* No. 6, for instance, the average number per plant when grown on a large scale in 1926-27 was 17.1, while the local *Gandiu* gave 28 suckers per plant, and the former commenced sucker formation two weeks later than the latter. The *Shengiu* No. 22, likewise, gave 19.2 suckers per plant, while the local *Shengiu* gave 27.9 per plant.

3. *Behaviour under irrigation.* A plant suitable for North Gujarat must be capable of growing well either dry or with irrigation, as the same variety is used for both purposes.

4. *Behaviour under manure and cultivation.* A plant suitable for North Gujarat must be capable of growing well under different modes of cultivation and with different doses of manure, as these two items vary much from field to field. For instance, our favourite No. 6 responds very well to the varying doses of manure and the different spacings, under which it is grown, while it is not so with any of the local varieties grown in the Kaira District.

#### *Leaf characters.*

1. *Size of leaves.* The leaves should be large. The yield at harvest depends on the weight of each leaf, combined with the number of living leaves at harvest. The weight per leaf depends on its area, the number of veins in it, and its thickness. The success of some of the selected types has been at least due to the large size of the leaves. Thus the typical leaf of *Gandiu* No. 6 has an area (1926-27) of 446 sq. cm., while the ordinary *Gandiu* local type has only an area of 390 sq. cm. *Movadiu* No. 20 has an average leaf area, of a typical leaf, of 373 sq. cm. (1926-27), while the local crop of the same variety showed only 305 sq. cm.

2. *Veins in the leaves.* It is clear that a large number of veins, and bigger veins, means heavier leaves, and hence types which have these, are very much liked by tobacco growers. The buyers for the local market have no objection to this, though, of course, it would be fatal for the foreign market. *Gandiu* No. 6 is characterised by large veins in the leaf, and this is one of the characters that make it popular.

3. *Thickness of leaves.* For local consumption, the growers and the consumers both prefer a thick leaf, and the thicker it is, the better it is liked for smoking. *Gandiu* No. 6 and *Piliu* No. 30 are the thickest leaved types and are much prized for smoking purposes. *Gandiu* No. 6, the most popular type, is not exceptionally thick, but is counted as "strong".

4. *Shape of the leaves.* There is no definite preference for a leaf of particular shape. Each variety has its leaf shape, to which it is expected to conform. *Piliu*

types, for instance, are expected to have a somewhat narrow tapering shape, while *Gandiu* types are expected to have broader and bigger leaves.

*Characters of the cured products.*

The cured leaf, for local use, should have a uniform yellowish colour with brownish golden-yellow spots. This is found in *Gandiu* No. 6, and extremely well developed in *Piliu* No. 30. In tobacco for chewing, the softness of the leaf fibre is specially wanted: this is found in *Movadiu* No. 20.

VI. DESCRIPTION OF CERTAIN STRAINS FROM KAIRA DISTRICT.

Nearly all the previous attempts at improving the quality of the tobacco grown in Northern Gujarat have had for their object the production of an export tobacco, and the method, generally adopted, had been the trial of imported seeds of high quality and the modification of the curing process so as to give a leaf which would imitate the production of America. The result of endeavours in this direction, has, however, been small. In 1922 a new line was taken up, and the basis of work, since that time, has been primarily the improvement of the *local* tobacco both in yield and quality. The strains to be described in the present Section represent selections from the local types obtained as a result of this policy, and they embody the typical characters of the best examples of these local tobaccos.

The characteristics which mark out the Gujarat varieties of *Nicotiana Tabacum* have been indicated earlier in the present paper. But in each of the varieties there is a wide variation, in the actual types under cultivation, in the cropping power and in other characters which are of direct or indirect agricultural and economic importance. This variation is clearly caused, to a large extent, by mixture and crossing of pure types, and this mixed character very markedly affects the evenness of the quality of the leaf put on the market. In no crop, perhaps, is this evenness of more importance than in tobacco, and it was felt that the isolation, maintenance, and spreading of a pure type, giving leaf of much more even quality, would itself be a great step in advance. Some of the strains isolated and maintained as a result of this policy have given very much more uniform as well as better market tobacco and have considerably increased the productive power of the land.

It is proposed to describe eight such strains, on the basis of three years' cultivation in pure line. Three of these are of the *Gandiu* variety (Nos. 1, 4 and 6), two of the *Movadiu* variety (Nos. 19 and 20), two of the *Piliu* variety (Nos. 28 and 30) and one of the *Shengiu* variety (No. 22).

GANDIU No. 1.

This strain is derived from a selection made originally in 1922-23, for large size of leaf, great vigour, and small number of suckers. The progeny of the selected plant varied in 1923-24, but from 1924-25, the seed secured from selfed plants has been uniform, and has bred absolutely true since then.



PLATE III.



Plant.



Leaf.

TOBACCO STRAIN No. 4.

The average length of the typical leaf and the leaf ratio, in plants grown for seed, were 42.3 cm. and 2.10 and in those grown for leaf they were 42.7 cm. and 2.05 respectively. The area of the leaf was, in 1926-27, 371 sq. cm. in plants for seed, and 511 sq. cm. in those for leaf. Thus the leaf area was the greatest in all the selections made. The ratio of the total length of the leaf to the distance from the point of greatest width to the tip (which indicates the shape of the leaf) was 2.34 in 1926-27. In other words, the greatest width was nearly at the middle of the leaf.

The leaves are darker than in *Gandiu* No. 4 and are similar to those in No. 6. The surface is less puckered than in strain No. 4. The average number of leaves, produced per plant allowed to seed, was 30.1. The number of living leaves at harvest, when the plants were nipped leaving 16 leaves per plant, was 12.8. The average leaf thickness, as measured by a micrometer screw, in the cured leaf, was .098 mm. It will be seen that the leaf was the thickest of all the selections.

The plant is short, the height being 70.4 cm. The suckers are few, though the number is greater and the suckers are larger than those in *Gandiu* No. 6. The average number of suckers removed was 23.6 per plant.

This is the latest flowering among *Gandiu* types, the period from planting to flowering being 89 days. The flowers are white with a tinge of pink and the inflorescence is compact. The yield of the type is low as the following figures, from single test plots of  $\frac{1}{80}$  acre with irrigation, show :—

1924-25	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	lb.
	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	18.2
1925-26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20.8
1926-27	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	17.4

The cause of low yield, in comparison with *Gandiu* Nos. 4 or 6, is not understood. It has been maintained as a type similar to No. 6, possibly suitable for crossing to get great vigour in the first generation of the cross.

#### GANDIU No. 4.

In 1922-23 this strain was picked out for purification and maintenance on account of the thickness and texture of the leaves. The progeny varied much in 1923-24, but since 1924-25 it has been constant in character under self-fertilization. Its characters are as follows :—

The average length of the typical leaf, and the leaf-ratio, in plants grown for seed, were 40.9 cm. and 1.89, and in plants grown for leaf they were 38.5 cm. and 1.82 respectively. The area of the leaf was, in 1926-27, 388 sq. cm. in plants grown for seed and 468 sq. cm. in plants for leaf. The ratio of the total length of the leaf to the distance from the point of greatest width to the tip (which indicates the shape of the leaf) was 2.57 in 1926-27. This means that the widest part of the leaf was nearest the tip. Though the leaf is broad, the area is not very large on this account.

The surface of the leaf is very markedly puckered. The average number of leaves produced per plant allowed to seed was 36.0, the number of living leaves at harvest, when the plants were nipped leaving 16 leaves per plant, was 11.9. Thus though the plant produces many leaves, it gives a crop of only a few leaves.

The average leaf thickness, as measured by a micrometer screw, in the cured leaf was .093 mm. Thus it is thinner than *Gandiu* No. 1.

This type is the tallest among the *Gandiu* selections, the average height being 91.9 cm. The suckers produced per plant are large in number, making it an expensive type to grow, and they arise earlier than in the other selected strains of *Gandiu*. The average number is 32.5 per plant.

On the whole, it is rather early flowering type, among the *Gandiu* selections, the period from planting to flowering being 82 days. The inflorescence is compact but the axis is long. The colour of the petals is pink.

The yield of the type was as follows on single test plots of  $\frac{1}{8}$  acre under irrigation :—

																lb.
1924-25	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	19.5
1925-26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	21.9
1926-27	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	16.7

Thus the yield is high in a dry year (1925-26), while it yields badly in a year of heavy rainfall. It has been maintained as a somewhat inferior type of *Gandiu* for cultivation.

#### GANDIU No. 6.

In the same year as the selections previously described were made (1922-23), the parent of the present strain was picked out on account of the large size of its leaves, their dark colour and the peculiar way in which they droop when ripe. From 1924-25, the plants secured from selfed seed were uniform, and it has bred true since that time.

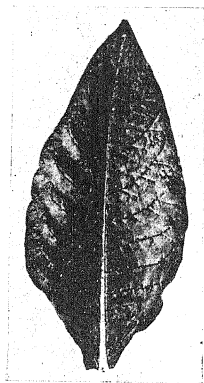
The average length of the typical leaf and the leaf-ratio, in plants grown for seed, were 42.1 cm. and 2.00; and in plants grown for leaf, they were 42.6 cm. and 2.07 respectively. The area of the leaf was, in 1926-27, 424 sq. cm. in plants grown for seed and 468 sq. cm. in plants grown for leaf. The leaf is almost as big as that in *Gandiu* No. 1.

The ratio of the total length of the leaf to the distance from the point of greatest width to the tip was 2.42 in 1926-27. Thus the point of the greatest width was a little above the middle of the leaf.

The colour of the leaves was attractively dark-green, but the surface is less puckered than that in *Gandiu* No. 4. The average number of leaves produced, per plant allowed to seed, was 31.5. Though this number is small as compared to other selections, the number of living leaves at harvest, when the plants were nipped leaving 16 leaves per plant, was 12.7, nearly one leaf per plant more over those obtained in *Gandiu* No. 4.



Plant.



Leaf.

TOBACCO STRAIN No. 6.



The average thickness of leaf, as measured by the micrometer screw, in the cured leaf was .093 mm.; the variation in this character from year to year was high, but the leaf is considered good, while it is "strong" for smoking.

This type is, on the whole, short, the average height being 71.7 cm. The number of suckers produced per plant is low, they form late in life of the plant, and they are small. The average number of suckers removed per plant was 22.8, and this means a distinct saving in expense.

The period from planting to flowering was 88 days. It is thus an average flowering type among the *Gandiu* strains. It is somewhat late at maturity. It has a characteristic, compact, short inflorescence, while the capsules are shorter and broader than in most of the local types. The colour of the petals is white, with a pinkish tinge.

The yield of the type was as follows on single test plots of  $\frac{1}{8}$  acre under irrigation :—

	lb.
1924-25 . . . . .	19.3
1925-26 . . . . .	22.4
1926-27 . . . . .	18.8

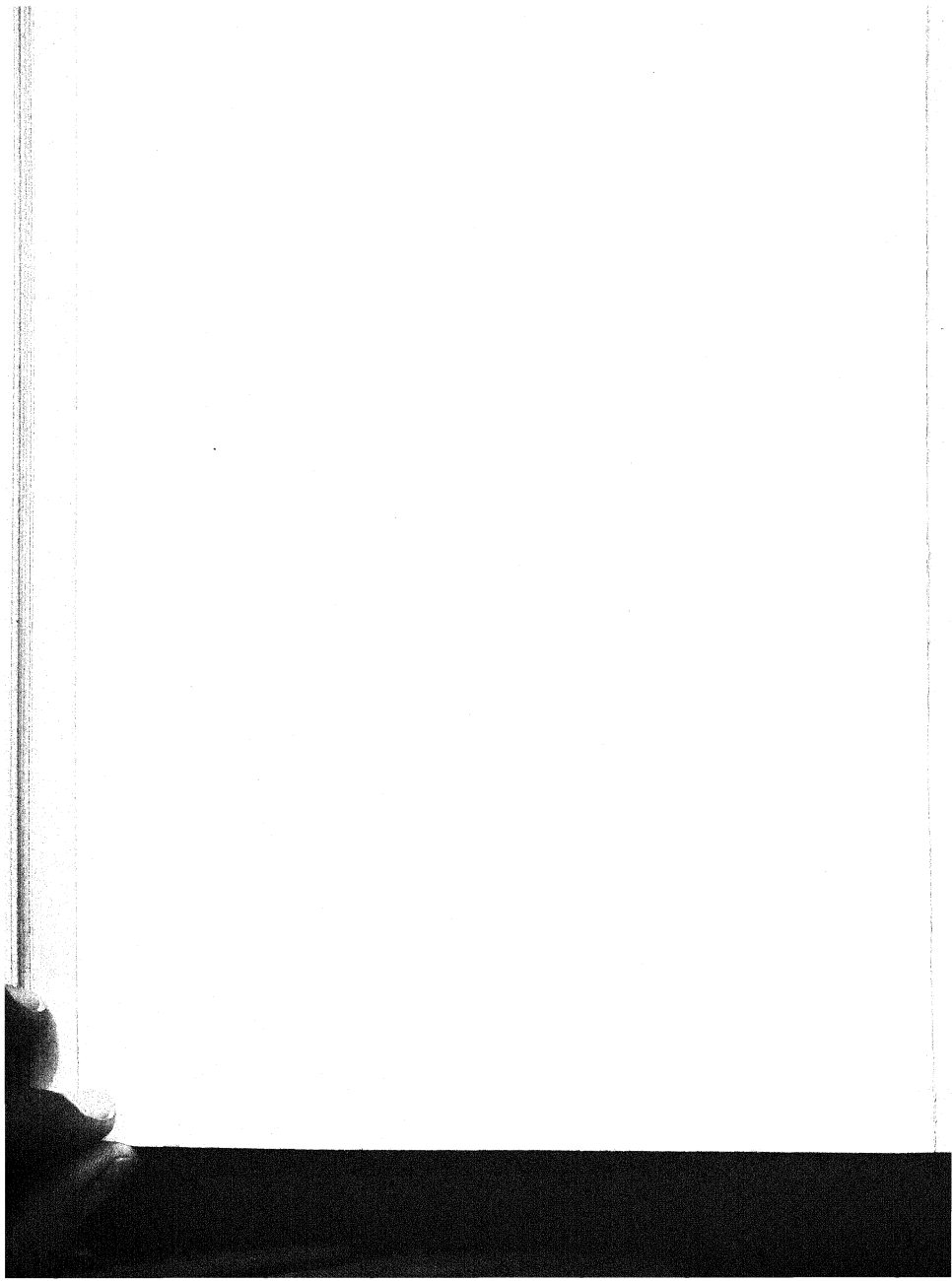
The average yield is high, and trials on a large scale have shown it to be, on the whole, the best yielding of the tobacco strains. Moreover, this type is somewhat frost resistant, that is, at the time of frost, the upper two or three leaves only out of the sixteen per plant are damaged, while in case of other strains and the local varieties, almost all the leaves are damaged by frost. This is a great quality in tobacco meant for Gujarat where the occurrence of cold spells is once in about five years.

It is maintained as being the best type hitherto found among *Gandiu* tobaccos. It has high yield, is cheap to grow and is frost-resistant. It is also preferred by consumers as it is strong. The cured leaf has better developed and finer golden yellow spots than the local tobacco. It is now grown widely in the Kaira District.

#### MOVADIU No. 19.

The history of this selection is similar to that of those already described. It was selected chiefly on account of its low habit of growth. It has been uniform since 1924-25 and bred true to type.

The average length of the typical leaf and the leaf-ratio were 38.6 cm. and 1.95 in plants grown for seed, and 39.8 cm. and 1.88 in plants grown for leaf. The leaf ratio was always under 2.0, which indicated the broad leaf characteristic of the variety. The ratio of the total length of the leaf to the distance from the greatest width to the tip was 2.34 in 1926-27. Thus the greatest width was nearly at the middle of the leaf. The area of typical leaf was, in 1926-27, 352 sq. cm. in case of plants for seed, and 448 sq. cm. in case of plants for leaf.



The average leaf thickness, as measured by the micrometer screw, in the cured leaf was .075 mm. The leaf in this strain is, therefore, thinner than in any other Gujarat selections. Moreover, the number of the veins in a leaf is 11.4, which is also low. Due to these causes, it is not looked upon with favour by the buyers, while the tobacco is considered mild.

This type is tallest among the selections made from Gujarat tobacco. The average height of the plants was 126.2 cm. In the early stages, it does not appear tall, but later on it shoots up and overtops all other types. The number of suckers produced per plant is large, though not so large as in *Movadiu* No. 19, but owing to the slow early growth of the plants, sucker production commences later by about a fortnight than in that strain. This is a distinct advantage in the matter of expense. The total average number of suckers was 31.0 per plant. The period from planting to flowering was 97 days. It is, as a matter of fact, the latest in flowering of all the selected types. It is also late in maturing. The inflorescence is compact though on long branches. The colour of petals is deep pink.

The yield of the cured leaf as tested on single plots of  $\frac{1}{16}$  acre under irrigation was as follows :—

	lb.
1924-25 . . . . .	16.0
1925-56 . . . . .	18.7
1926-27 . . . . .	14.6

The *Movadiu* tobaccos are generally grown dry, and when this strain is grown dry, in its own locality, it yields very well and better than No. 19. It is, in fact, replacing the local *Movadiu* tobaccos. It has the special quality that the veins of the leaf have soft fibre, and hence the leaf is particularly suitable for chewing. It is maintained because of the demand for this type in the Thasra Taluka (Kaira District) and for the interest of the extremely broad leaves, the tallness of the plant, the most deeply pink coloured petals, and the late production of suckers.

#### SHENGIU No. 22.

This was another selection made in 1922-23 from the second variety grown without irrigation, in the Thasra Taluka of the Kaira District. The progeny of 1923-24 was variable. One type was found in 1924-25 with desirable characters which has bred true since then. This is *Shengiu* No. 22.

The average length of the typical leaf and the leaf-ratio was 42.1 cm. and 2.65 in plants grown for seed, and 41.7 cm. and 2.88 in plants grown for leaf. The average area of the leaf was, in 1926-27, 288 sq. cm. in plants grown for seed and 313 sq. cm. in plants grown for leaf. The ratio of the total length of the leaf to the distance from the point of the greatest width to the tip was 2.26, that is to say, the greatest width was nearly at the centre of the leaf.

The average number of leaves produced per plant kept for seed was 30·7. The number is low for this small-leaved type. The number of living leaves at harvest when the crop is grown for leaf, keeping 16 leaves per plant at nipping, was 12·4. The thickness of the leaves, as measured by a micrometer screw, in the cured leaf was ·092 mm. This is more than the usual thickness of the leaves of this strain. The average number of veins in a leaf was 10·9. The plants of this type are usually fairly tall, but the height is very much affected by the weather condition in some seasons, as in 1925-26 when the rain was deficient. The average height of the plants was 90·4 cm. The number of suckers produced per plant is 29·4 about the average for Gujarat types. The period from planting to flowering was 69 days. It is one of the earliest flowering types, and approaches *Piliu* No. 30, described later. The inflorescence is long and somewhat sparse and the colour of the petals is pink. It comes to maturity early, and the yield of the cured leaf, as found in single test plots of  $\frac{1}{80}$  acre, under irrigation, was as follows :—

	lb.
1924-25 . . . . .	16·0
1925-26 . . . . .	14·9
1926-27 . . . . .	14·2

The yield is thus lower, under irrigation, than those strains previously described, but as a very early tobacco, grown dry, it has many advantages, and it is rapidly replacing the mixture of *Shengiu* Types hitherto usually grown. The colour of the finished product is, however, poor.

#### PILIU No. 28.

This type, was selected from a field of the *Piliu* tobacco in 1922-23. It was uniform in 1924-25 and has bred true since that time.

The average length of the typical leaf and the leaf-ratio in plants grown for seed was 40·6 cm. and 2·16 and in those grown for leaf 40·4 cm. and 2·19. The leaf is thus rather broader than is usual in *Piliu* types. Also the narrow portion at the base of the leaf is not so long as is usual with strains of *Piliu*. The area of the leaf was, in 1926-27, 335 sq. cm. in plants grown for seed and 423 sq. cm. in plants grown for leaf. It occupies the intermediate position, in size of the leaf, between *Gandiu* and *Piliu* tobaccos. The ratio of the total length of the leaf to the distance from the widest part of the leaf to the tip was 2·18, in 1926-27, that is to say, the greatest width is quite at the centre.

The average number of leaves produced per plant kept for seed was 33·0, the number of living leaves at harvest in plants kept for leaf, and nipped keeping 16 leaves per plant, was only 11·8 per plant. The thickness of the leaves as measured by a micrometer screw, in the cured leaf, was ·092 mm. Thus the leaves are thick. The number of veins in a leaf is 10·5, and they are not very prominent.



Plant.



Leaf.

TOBACCO STRAIN No. 28.



Plant.



Leaf.

TOBACCO STRAIN No. 30.

The plants of this type are usually tall, the average height being 96.6 cm. The number of suckers produced per plant is 30.6 about the average of the types considered here.

The period from planting to flowering was 68 days on the average. It is one of the early types, but not so early as *Shengiu* No. 22 or *Piliu* No. 30. It is the only big leaved early type which it has been possible to isolate.

The yield of the cured leaf, as tested in single plots of  $\frac{1}{80}$  acre, under irrigation, was as follows :—

	lb.
1924-25 . . . . .	14.5
1925-26 . . . . .	14.1
1926-27 . . . . .	15.0

Thus the yield is higher than that in *Piliu* No. 30 described later and is almost the same as that of *Shengiu* No. 22. The leaves give a product of a good colour and are thick. This strain is in fact replacing local mixed *Piliu* tobacco, with the advantage of large leaves and hence higher yield.

#### PILIU No. 30.

This strain, which is a typical *Piliu* tobacco, was selected from a field of the crop of 1922-23, chiefly on account of the small liner leaves and rather dwarf habit of growth. It was found to be uniform two years later, and has bred true since that time.

The average length of typical leaf and the leaf-ratio, in plants grown for seed, were 33.4 cm. and 2.56, and in plants grown for leaf, 36.9 cm. and 2.61. Thus the leaves are very narrow. The area of the leaf was, in 1926-27, 228 sq. cm. in plants grown for seed, and 281 sq. cm. in plants grown for leaf. Thus the leaf is small, the smallest among the selections, and has only half the area of the large-leaved *Gandiu* types. The thickness of the leaves, as measured by a micrometer screw, in the cured leaf was .097 mm. Hence the leaves are very thick. They have the smallest number of veins, viz., 10.0 per leaf.

The ratio of the total length of the leaf to the distance from the widest part of the leaf to the tip was 2.15, that is to say, the greatest width was just at the centre. The average number of leaves produced per plant kept for seed was 31.5. The number of living leaves at harvest, in plants kept for leaf and nipped keeping 16 leaves per plant, was 11.1. The latter number is lower than in any other type.

The plants are tall, the average height being 86.5 cm. The number of suckers produced per plant is 22.4. It is below the average but their formation begins very early, earlier than in any other strain. The period from planting to flowering was 68 days. It is thus the earliest flowering type. It is also the earliest maturing type, earlier than *Gandiu* No. 6 by no less than six weeks. The inflorescence is

long and very sparse, some of the flowering branches being longer than the main axis. The seed capsules are small, narrow and long and have few seeds. The flower petals are pink.

The yield of the cured leaf found in single test plots of  $\frac{1}{16}$  acre, under irrigation, was as under :—

	lb.
1924-25 . . . . .	15.8
1925-26 . . . . .	12.8
1926-27 . . . . .	9.5

The yield is thus the lowest among the selections. Its importance lies in its exceptionally good quality for the local market. It is considered the thickest in point of leaf and strongest for smoking. The cured product has a very uniform golden yellow colour with fine spots. It is maintained on account of these fine quality characters.

#### VII. IMPROVEMENTS.

The eight strains derived from tobaccos grown in the Kaira District, which have now been described, may be taken as typical of the plants under cultivation in that area. Out of these eight strains, three have already been established in large-scale cultivation, chiefly on account of their superior yield to the corresponding mixture of types already in cultivation, but also in the case of at least of *Gandiu* No. 6 on account of its greater market value.

As regards the increased yield, records taken from large scale cultivation may be given, to indicate the extent to which the amount of product has been augmented. Some have been obtained on the Tobacco Research Station, Nadiad, others are from cultivators' fields.

#### GANDIU No. 6.

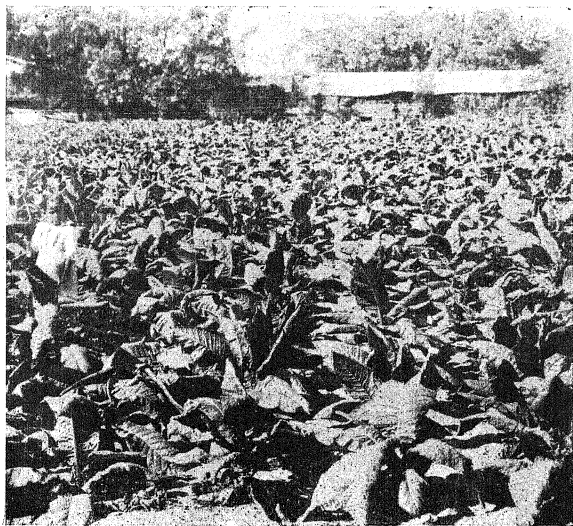
##### (1) Crop at Tobacco Research Station, Nadiad.

	WEIGHT OF CURED TOBACCO PER $\frac{1}{16}$ ACRE			
	1924-25	1925-26	1926-27	Average
	lb.	lb.	lb.	lb.
<i>Gandiu</i> No. 6 . . . . .	38.5	40.8	35.6	38.3
<i>Gandiu</i> local . . . . .	33.7	35.6	30.6	33.3

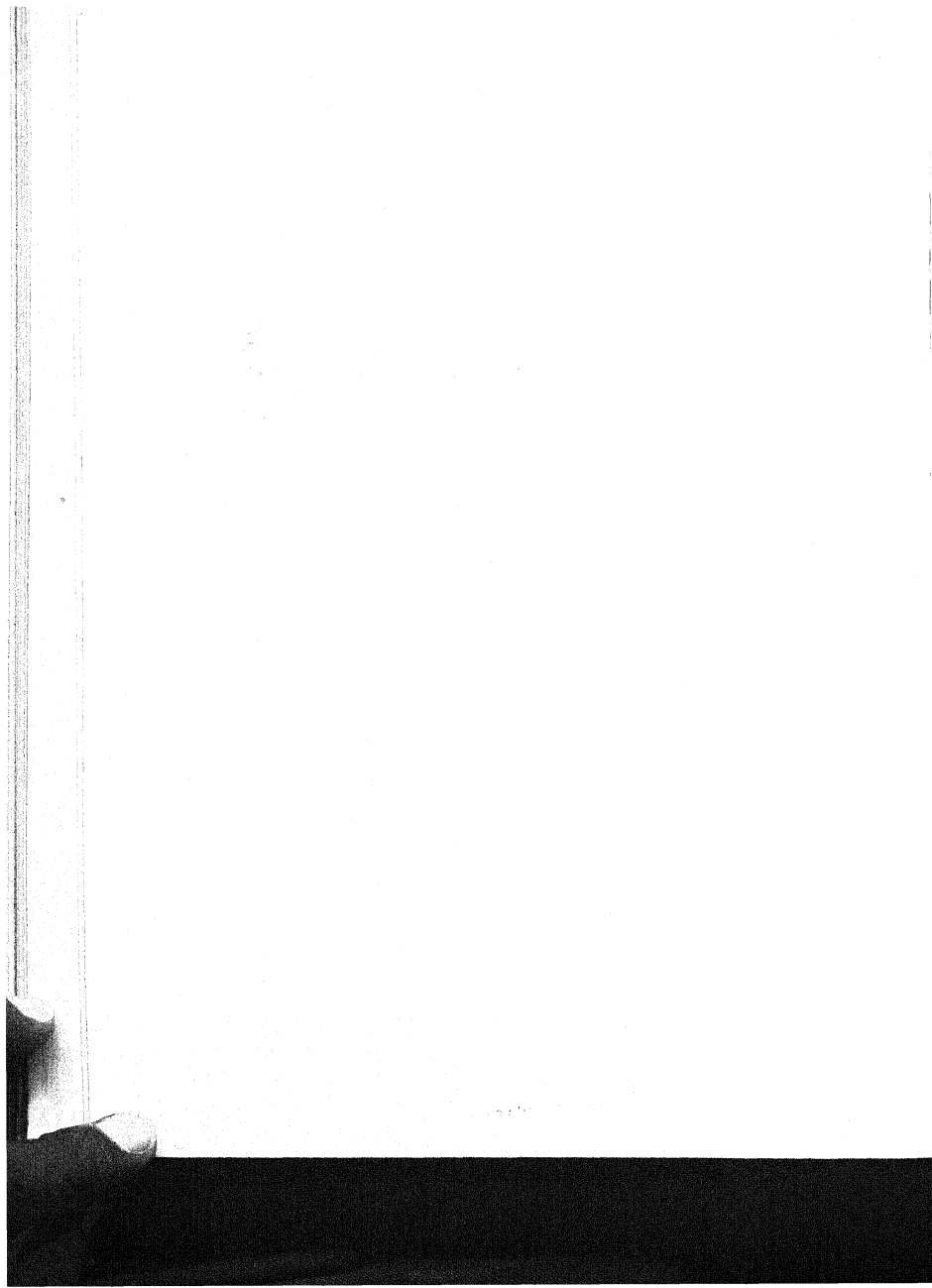
Increase in yield over the local=15 per cent.



Field of Gandiu No. 6.



Field of local tobacco.



(2) *Crop raised by tobacco growers of Nadiad Taluka.*

	WEIGHT OF CURED TOBACCO PER ACRE			
	1924-25	1925-26	1926-27	Average
	lb.	lb.	lb.	lb.
<i>Gandiu</i> No. 6 . . . . .	1,906	1,148	931	1,328
Local seed . . . . .	1,647	980	809	1,145

Increase in yield over the local=16 per cent.

The area under No. 6, as recorded in these tests, was 1.10 acres in 1924-25, 3 acres in 1925-26 and 13 acres in 1926-27.

(3) *Crop raised by tobacco growers of Anand Taluka.*

	WEIGHT OF CURED TOBACCO PER ACRE		
	1925-26	1926-27	Average
	lb.	lb.	lb.
<i>Gandiu</i> No. 6 . . . . .	1,212	1,167	1,189
Local seed . . . . .	885	908	894

Increase in yield over the local=33 per cent.

The area under No. 6, as recorded in these tests, was 15 acres in 1925-26 and  $6\frac{1}{2}$  acres in 1926-27.

## MOVADIU No. 20.

(1) *Crop at Tobacco Research Station, Nadiad.*

	WEIGHT OF CURED TOBACCO PER $\frac{1}{10}$ ACRE			
	1924-25	1925-26	1926-27	Average
	lb.	lb.	lb.	lb.
<i>Movadiu</i> No. 20 . . . . .	36.4	33.4	25.6	31.7
Local seed . . . . .	32.4	32.5	23.7	29.5

Increase in yield over the local=8 per cent.

(2) *Crop raised by tobacco growers of Thasra Taluka.*

	WEIGHT OF CURED TOBACCO LEAF PER ACRE			
	1924-25	1925-26	1926-27	Average
	lb.	lb.	lb.	lb.
<i>Moradin</i> No. 20 . . . . .	1,120	..	822	971
Local seed . . . . .	960	..	700	830

Increase in yield over the local=17 per cent.

The area under No. 20, as recorded in these tests, was 1.0 acre in 1924-25 and  $3\frac{1}{2}$  acres in 1926-27. Here the tobacco was grown without irrigation.

## SHENGIU No. 22.

(1) *Crop at Tobacco Research Station, Nadiad.*

	WEIGHT OF CURED LEAF PER $\frac{1}{10}$ ACRE			
	1924-25	1925-26	1926-27	Average
	lb.	lb.	lb.	lb.
<i>Shengiu</i> No. 22 . . . . .	36.4	32.4	26.2	31.7
Local seed . . . . .	31.0	26.9	24.3	27.4

Increase in yield over the local=15 per cent.

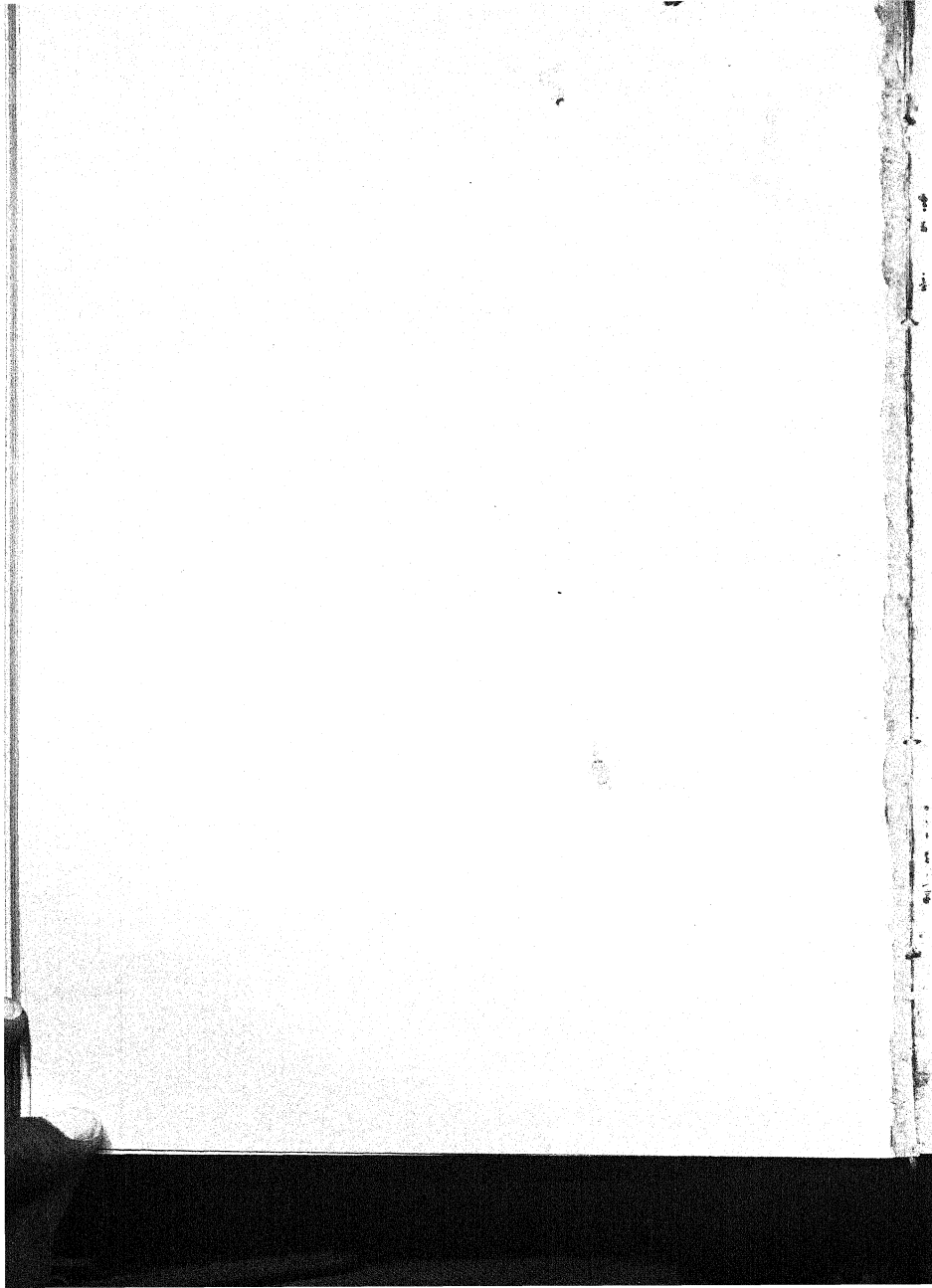
(2) *Crop raised by tobacco growers of Thasra Taluka.*

	WEIGHT OF CURED LEAF PER ACRE			
	1924-25	1925-26	1926-27	Average
	lb.	lb.	lb.	lb.
<i>Shengiu</i> No. 22 . . . . .	1,250	509	..	879
Local seed . . . . .	1,100	470	..	785

Increase in yield over the local=12 per cent.

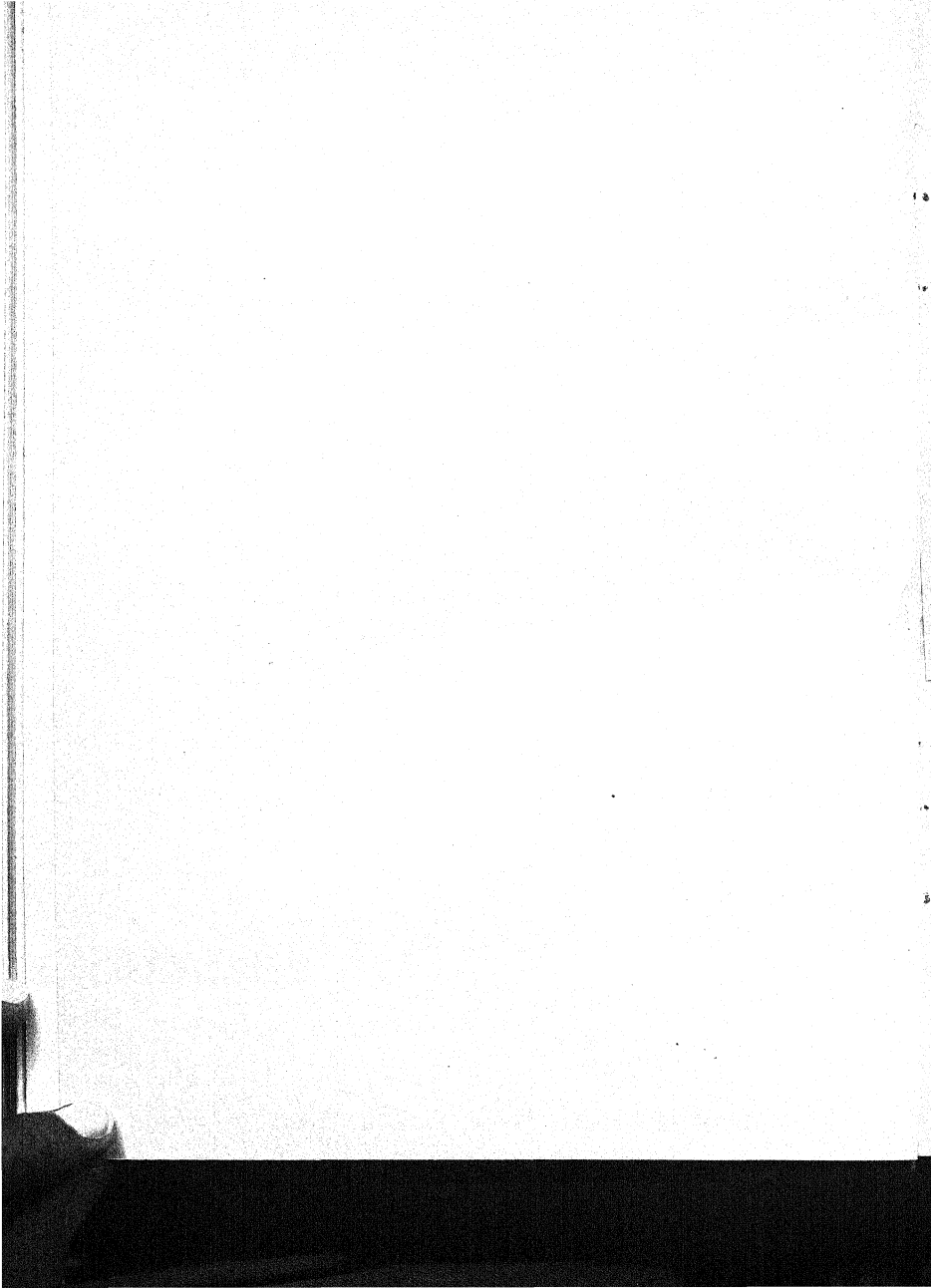
The area under No. 22, as recorded in these tests, was 1.0 acre in 1924-25, and 2.0 acres in 1925-26. Here the tobacco was grown without irrigation.

It will thus be seen that several of the strains isolated from the local tobaccos have given consistently larger yields of the cured leaf, both on the Experimental Station and in the fields of tobacco growers. Taken in conjunction with the fact that a more even produce is secured, this furnishes a reason why each of the three recorded above (*Gandiu* No. 6, *Movadiu* No. 20 and *Shengiu* No. 22) is spreading rapidly in its appropriate area.



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#### ERRATA.

In Plate V, figures 4 and 5 have been printed without the correct purple tinge. Plate VI is also deficient in purplish tinge in the capsules.

*Page 136, line 28.*—Delete figures "13" and "22".

*Page 142, line 27.*—For "all simple", read "divided".

*Page 143, line 30.*—For "all" read "mostly".

MGIPC—M—158 CPB—27-10-30—600.



## STUDIES IN INDIAN OIL SEEDS.

### (4) THE TYPES OF *Sesamum indicum*, D. C.

BY

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(Received for publication on 19th November 1929.)

#### I. INTRODUCTION.

*Sesamum* is an annual plant cultivated throughout the tropical regions of the globe for the oil obtained from its seeds.

The diversity of names<sup>1</sup> clearly shows that its cultivation in Asia dates from a very early epoch. In *sanskrit* it is called *tila*, in Chinese *moa*, in Japanese *koba*, in Malay *widju*. The name sesam is common to Greek, Latin, and Arabic, with trifling variations of letter.

The botanical evidence alone might lead to the supposition that *Sesamum* is originally a native of Africa, in which continent there are some eight or nine truly wild forms, and where the present species is known to have been cultivated from remote times. De Candolle<sup>2</sup> is of opinion that, though *Sesamum* has not hitherto been recorded as found wild in any of the warmer tracts of Central Asia, it is cultivated everywhere in the Himalayas, in Afghanistan, Persia, Arabia and Egypt. If not originally native of the warm temperate tracts of India, it was probably brought to India before it found its way to Egypt and Europe. In the *Ain-Akbari* (1590) frequent reference is, however, made to both black and white seeded forms so that there is abundant evidence for its having been an important crop in India for at least the past 300 years.

In India, however, it may be described, as a crop of the warm temperate, or sub-tropical tracts, being grown as an autumn or winter crop in the warmer parts, and as a summer one, in the colder districts.

---

<sup>1</sup> De Candolle, Origin of cultivated plants, 1904, p. 420.

<sup>2</sup> Watt, Commercial Products of India, 1908, p. 982.

*Statement showing the average annual area and the outturn per acre of sesamum in British India.<sup>1</sup>*

Province	Average <sup>2</sup> area in acres	Outturn per acre in lb.
Burma . . . . .	1,050,480	225
Madras . . . . .	737,918	300
Central Provinces . . . . .	534,666	225
Bombay . . . . .	925,997	400
United Provinces . . . . .	223,186	280
Bihar and Orissa . . . . .	205,800	..
Bengal . . . . .	157,140	500
Punjab . . . . .	119,093	..
Ajmer-Merwara . . . . .	22,235	..
Assam . . . . .	19,595	450
N. W. F. Provinces . . . . .	3,177	..
Coorg . . . . .	156	..
Delhi . . . . .	86	300

The figures in the above statement show that the total average annual area in this crop is over three million acres and the outturn per acre ranges from 225 to 500 lb.

The relative importance of the provinces in the production of the crop is shown in the above statement. Burma is the largest grower with 31·6 per cent. of the total area, the principal growing districts in the province being Myingyan, Magwe, and

<sup>1</sup> Agricultural Statistics of India, 1926-27, Vol. I, p. 24.

<sup>2</sup> The average is based on 5 years' figures, 1923-1927.

Lower Chindwin. Madras grows 22.2 per cent., the largest areas being at Godavari, Vizagapatam and North Arcot. Central Provinces grows 16.2 per cent., mostly in Sambalpore, Raipur and Jubbulpore districts. About 6 to 7 per cent. of the total area is contributed by each of the provinces of Bombay, United Provinces, and Bihar and Orissa.

*Total quantities and value of sesamum oil and seeds exported from British India.<sup>1</sup>*

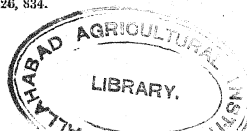
Quantity	1923	1924	1925	1926	1927	Annual average value of export in rupees
<b>Oil—</b>						
Cwt. . . . .	4,940	6,890	5,775	5,052	4,140	..
Gallons . . . .	55,299	71,161	62,691	56,582	46,361	..
Value in Rs. . .	1,60,063	2,00,432	1,70,384	1,75,276	1,61,521	1,75,335
<b>Seeds—</b>						
Tons . . . . .	554	552	309	214	310	..
Value in Rs. . .	1,65,862	1,75,895	87,936	62,698	91,161	1,16,710
TOTAL RS.						2,02,045

It is clear from the last two statements that most of the *Sesamum* grown is consumed in the country itself, and nearly three hundred thousand rupees worth is exported annually in the form of oil and seeds. Most of it goes to Arabian Gulf ports, D'Jibouti, Obokh and Independent Somali ports.

The foregoing returns show that the crop value, if calculated at the lowest yield of 200 lb. per acre and at an average price of Rs. 10 per 82 lb., amounts to over 8 crores of rupees. Thus, *Sesamum* plays an important part in the agriculture of India and is an article of considerable value in the export trade as well.

Although the crop has been so widely distributed and cultivated more or less all over the country from time immemorial, it appears that no attempts have ever been made to isolate the existing unit species of which the present crop is composed. In order to accomplish this, a collection of mixed samples of seeds from all over India and Burma was made in 1925. The various samples were sown at Pusa, and a large number of single plants from each were selected and selfed. The process of selfing,

<sup>1</sup> Annual Statement of the Sea-borne Trade of British India, 1927, Vol. II, pp. 826, 834.



and of eliminating the heterozygotes was continued for several years. The unit species breeding true were then studied and classified and this work forms the subject matter of the present paper.

The continuous bagging and selfing of plants did not produce any falling off in plant vigour.

Localities from which original samples of seeds were obtained and the types isolated from them, were as follows :—

Province	Locality	Types isolated at Pusa
Bombay . . . . .	Sukkur . . . . .	1, 3.
	Ahmedabad . . . . .	2, 17, 21.
	Panchualals . . . . .	9.
Punjab . . . . .	Hoshiarpur . . . . .	6.
United Provinces . . . . .	Aligarh . . . . .	7.
	Fyzabad . . . . .	28, 29.
Bengal . . . . .	Pabna . . . . .	30.
	Faridpur . . . . .	18.
	Murshidabad . . . . .	5.
	Nadia . . . . .	26.
Central Provinces . . . . .	Saugor . . . . .	27.
	Chindwara . . . . .	10.
Assam . . . . .	Surma Valley . . . . .	25.
Madras . . . . .	Bobbili-Vizagapatam . . . . .	19.
	Chicocole-Ganjam . . . . .	15.
	Vizianagram . . . . .	16.
Burma . . . . .	Meiktila . . . . .	4.
	Layhmankgwa . . . . .	13, 22.
	Poseingyi . . . . .	20.
	Semapan . . . . .	11, 14, 24.
	Mandalay . . . . .	12.
	Shakafe . . . . .	8.
	Allanmyo . . . . .	23.

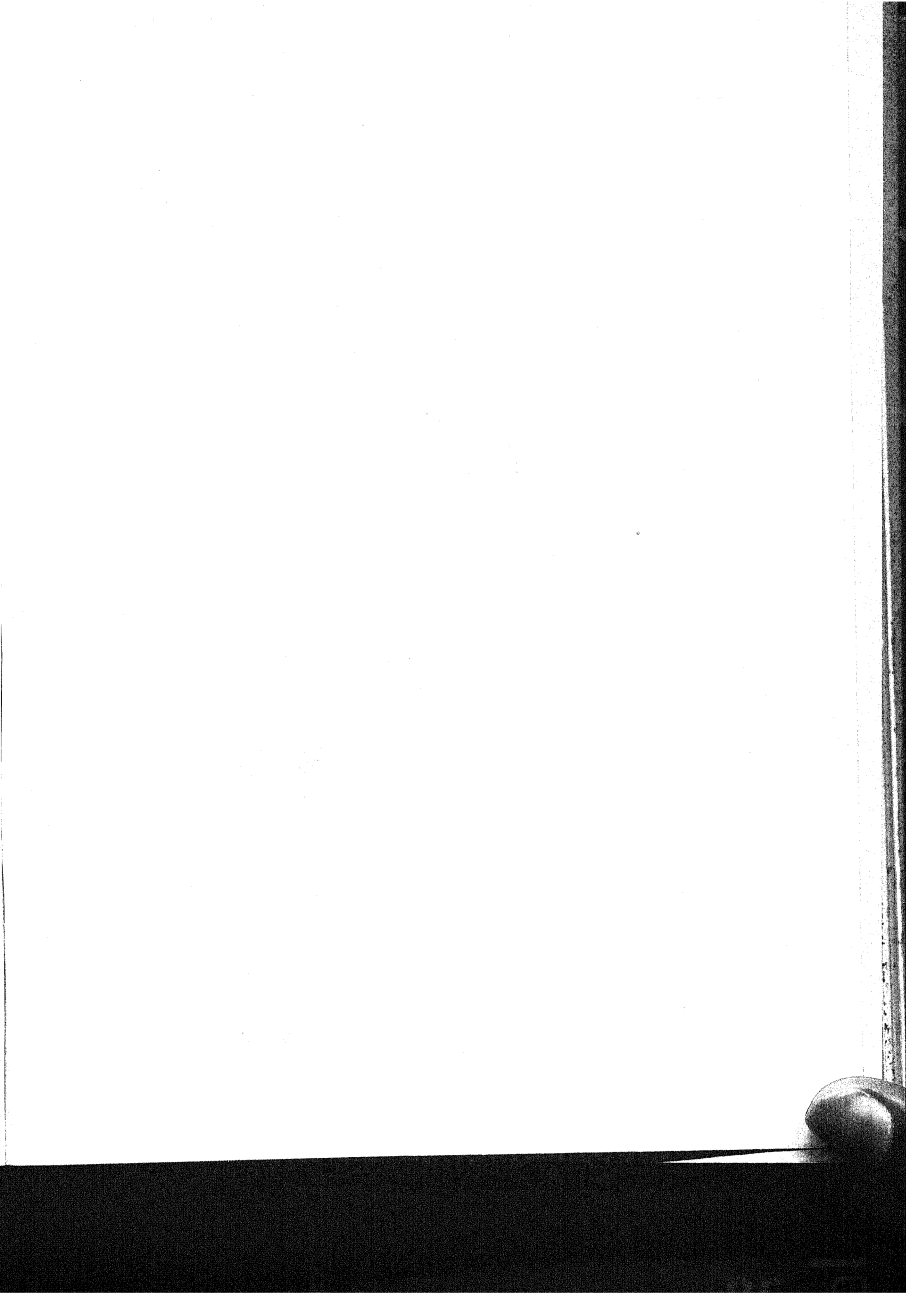
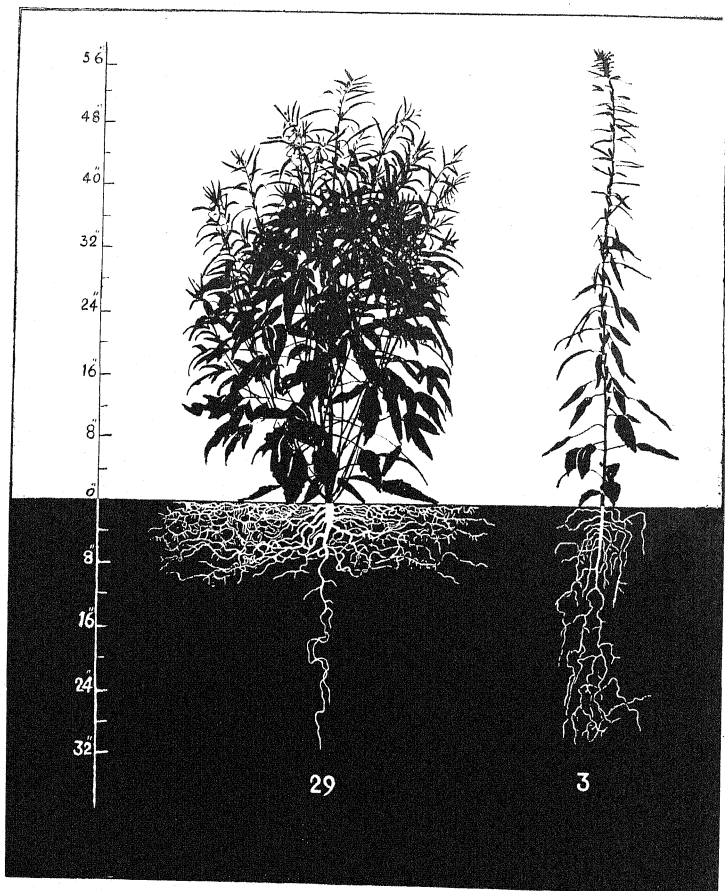


PLATE I.



The relation between the root and shoot developments in early and late types.

Type 29, late.

Type 3, early.

## II. GENERAL BIOLOGY.

## 1. Root System.

Remarkable differences in the root systems of early and late types of *Sesamum* have been observed. The early types generally grow more rapidly than the late ones, but are poorly branched and possess a poor root system. The main root goes about 3 feet deep and bears a few secondary and tertiary roots. The late types grow comparatively slowly, but are profusely branched and possess a stronger root system. The main root goes more than three feet deep and bears an enormous number of secondary and tertiary roots close to the surface. There is a definite correlation between the root and shoot development. These points are well illustrated in the original root drawings in Plate I.

Variation in the root systems of unit species has been studied in the case of some other crops, that is, linseed (*Linum usitatissimum* L.),<sup>1</sup> lentils (*Ervum lens* L.),<sup>2</sup> and *khesari* (*Vicia sativa* L.).<sup>3</sup> In all these crops it was found that the deep-rooted types were endemic in Peninsular India and that this type of root was characteristic of the black cotton soils of this area. In the case of *Sesamum*, this division of the unit species into deep-rooted and shallow-rooted types is not diagnostic of the distinction between types native to Peninsular India and to the alluvium.

The root formation of all the early types whether they are native to the Gangetic alluvium, Peninsular India or Burma is practically the same as that of Type 3 (Plate I), and the root formation of nearly all the late types is similar to that of Type 29 (Plate I); whereas the root systems of types which are medium in maturity are intermediate between the first two forms. The following Table shows the geographical distribution of early, late and intermediate types.

TABLE I.

Province	TYPES		
	Early	Medium	Late
Bombay . . . . .	1, 3, 9 . . .	2, 21.	..
Burma . . . . .	4, 8, 11, 13, 14, 20, 22, 23, 24.	12 . . .	..
United Provinces . . . . .	7 . . . . .	..	28, 29.
Punjab . . . . .	6 . . . . .	..	17
Madras . . . . .	15, 19 . . .	16 . . .	..
Bengal . . . . .	..	18, 26 . .	5, 30.
Assam . . . . .	..	..	25.
Central Provinces . . . . .	..	10, 27 . .	..

<sup>1</sup> Howard, and A. R. Khan. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. XII, No. 4, 1924.

<sup>2</sup> Shaw, and R. D. Bose. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. XVI, No. 6, 1928.

<sup>3</sup> Howard, and A. R. Khan. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. XV, No. 2, 1928.

In India the crop is grown in many different types of soil, from the poorest sandy soils to the richest clayey lands. The crop does not require much care or heavy manuring. It is generally classed as a monsoon crop but in Madras where the soils are sandy it is sown in May-June, provided rains are sufficient. As heavy rains are detrimental to the well-being of the crop, in Dacca, Eastern Bengal and Burma, where the soils are retentive of moisture, the early varieties are sown as early hot weather crops. In Central Provinces and Bombay, on black cotton soil, it is sown as an autumn or early cold weather crop.

## 2. Flowering.

The flowers are borne in racemes, either solitary or fascicled 2-3 together, in acropetal succession on short pedicels, in the axils of the upper leaves. When borne singly, the two rudimentary buds in the axil remain undeveloped.

Usually 1 to 2 flowers open at the same time on any one inflorescence, while in types with three flowers in the axil, about 3 to 4 flowers open at a time. The early varieties start flowering about 4 weeks after sowing, while the late ones begin to flower a fortnight later than the earlier varieties. On a bright clear day the flowers of early types open at about 5 to 6 A.M. and fade soon after midday, the corolla being shed without closing in the afternoon. But the flowers of the late types open at about 5 to 7 A.M. in the morning, the corolla being shed without closing late in the evening.

In September and October 1929 the following observations were made on this point:—

TABLE II.

*Observations on the time\* of opening and closing of the flowers.*

24th September 1929. Max. temp. 94°F. Min. temp. 78°F. Humidity 83 per cent.

Type 3 (white seeded early).

No. of flower	Time of bursting of anthers	Time when the opening of the flower was completed	Time of shedding of corolla
1 . . . . .	3-20	5-29	11-32
2 . . . . .	3-30	5-20	12-20
3 . . . . .	3-50	4-55	11-2
4 . . . . .	3-52	4-40	11-4
5 . . . . .	3-51	4-37	12-25
6 . . . . .	3-15	5-50	14-0
7 . . . . .	3-22	5-23	15-35
8 . . . . .	3-18	4-58	12-20
9 . . . . .	3-17	6-4	13-20
10 . . . . .	3-0	5-0	13-25
11 . . . . .	3-12	6-25	11-45
12 . . . . .	3-32	5-10	12-25

\* The 24-hour notation is used.

TABLE III.

*Observations on the time\* of opening and closing of the flowers.*

27th September 1929. Max. temp. 92°F. Min. temp. 76·8°F. Humidity 79 per cent.

Type 15 (brown seeded early).

No. of flower	Time of bursting of anthers	Time when the opening of the flower was completed	Time of shedding of corolla
1 . . . .	3-5	5-32	9-35
2 . . . .	3-17	5-40	9-48
3 . . . .	3-6	5-15	10-55
4 . . . .	3-7	Flower damaged	
5 . . . .	3-8		9-55
6 . . . .	3-9		10-25
7 . . . .	3-10		12-45
8 . . . .	3-10	5-58	10-57
9 . . . .	3-12	6-5	12-5
10 . . . .	3-21	6-0	11-50
11 . . . .	3-14	4-48	15-34
12 . . . .	3-15	5-57	12-10

\* The 24-hour notation is used.

TABLE IV.

*Observations on the time\* of opening and closing of the flowers.*

23rd October 1929. Max. temp. 85·5°F. Min. temp. 65°F. Humidity 81 per cent.

Type 28 (black seeded late).

No. of flower	Time of bursting of anthers	Time when the opening of the flower was completed	Time of shedding of corolla
1 . . . .	4-30	5-31	15-15
2 . . . .	4-17	6-20	12-0
3 . . . .	4-48	5-34	15-38
4 . . . .	5-0	6-59	14-34
5 . . . .	4-49	6-16	12-55
6 . . . .	4-47	6-50	18-10
7 . . . .	4-50	7-0	19-8
8 . . . .	4-27	6-55	13-30
9 . . . .	4-58	7-40	14-35
10 . . . .	Flower damaged	—	—
11 . . . .		6-7	15-0
12 . . . .	3-59	5-59	15-10

\* The 24-hour notation is used.

TABLE V.

*Observations on the time\* of opening and closing of the flowers.*

25th October 1929. Max. temp. 86.5°F. Min. temp. 67°F. Humidity 75 per cent.  
Type 29 (black seeded late).

No. of flower	Time of bursting of anthers	Time when the opening of the flower was completed	Time of shedding of corolla
1 . . . .	3-55	6-35	14-27
2 . . . .	3-58	4-48	14-30
3 . . . .	3-57	5-23	20-25
4 . . . .	4-0	6-3	18-31
5 . . . .	4-10	5-9	15-8
6 . . . .	4-0	4-51	12-30
7 . . . .	4-15	6-15	14-30
8 . . . .	4-20	6-30	15-19
9 . . . .	3-35	5-55	14-20
10 . . . .	3-54	5-3	15-35
11 . . . .	4-18	5-27	15-6
12 . . . .	3-37	4-50	18-30

\* The 24-hour notation is used.

### 3. Pollination and fertilization.

The method of pollination and fertilization in *Sesamum* described by Fruwirth<sup>1</sup> and Howard<sup>2</sup> is as follows :—

“ In the mature flower bud before the flower opens, the four unripe anthers are much below the stigma which at this period is not receptive. The anthers begin to burst longitudinally after 4 A.M. and commence to liberate their pollen. At this time the two hairy lobes of the bifid stigma begin to separate and become receptive. The position of the anthers and stigma at this period is as follows. The fork of the bifid stigma and the centre of the two long stamens are at the same level, while the

<sup>1</sup> Fruwirth. *Die Zuchtung der landw. Kultur pflanzen* Bd. V, 1912.

<sup>2</sup> Howard, Howard, and A. R. Khan. *Mem. Dept. of Agri. India, Bot. Ser.*, Vol. X, No. 5.

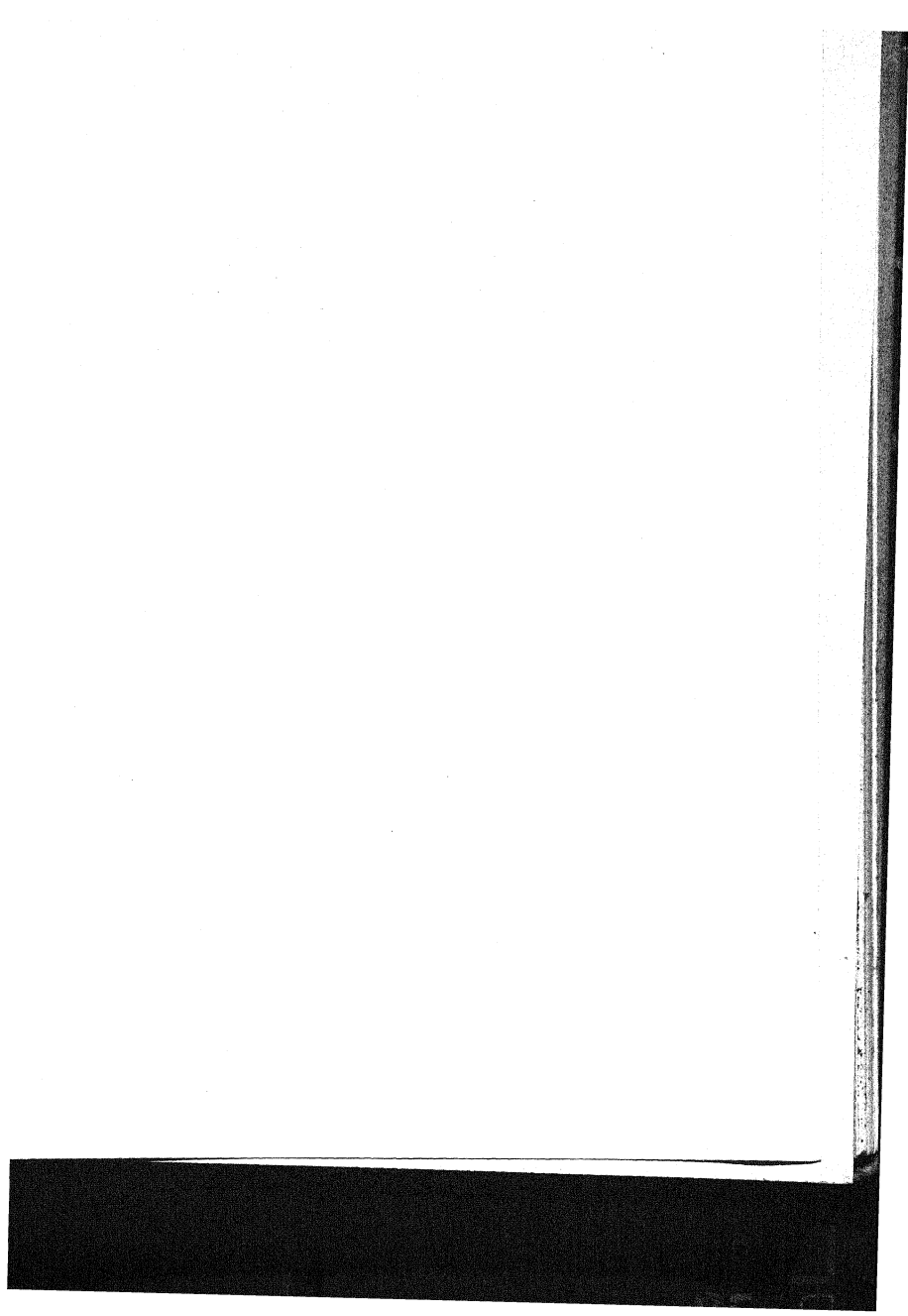
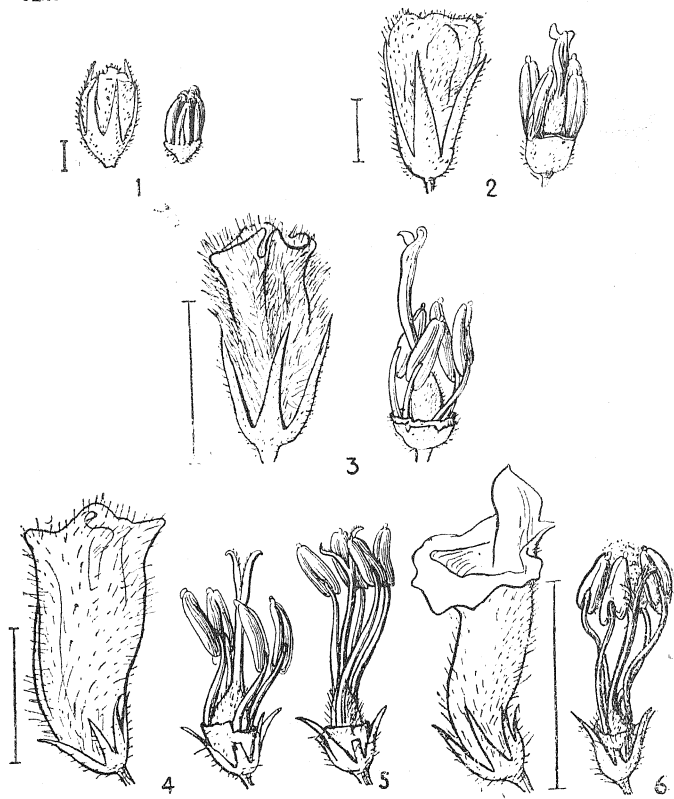


PLATE II.



1. Bud stage 2 days before flowering.

2. Bud stage 1 day before flowering.

3. Bud stage in the forenoon before flowering.

4. Bud stage late in the evening previous to flowering.

5. Bud stage early in the morning previous to flowering.

6. Bud stage next morning when the flower is completely opened.

The vertical line (I) drawn by the side of each drawing represents the natural height of the flower in each stage.

anthers of the two short stamens are at a lower level. The stigmas are irritable and the two lobes separate when touched, all the organs are practically in contact, and self-pollination is easy. By 5 o'clock in the morning the stigma is generally covered with pollen and as insects were not observed till 6 A.M., a great deal of self-pollination is bound to take place. Very frequently, however, the anthers in some flowers do not develop but remain aborted, and turn brown without shedding any pollen. In these cases the visit of bees easily brings about cross-pollination and it is probable that most of the cross-fertilization which takes place in this crop is due to this cause."

According to our observations at Pusa we confirm the above description and have found that the anthers begin to burst soon after 3 A.M. The various stages in the development of *Sesamum* flower buds are shown in Plate II.

#### 4. Hybridization.

In order to study the inheritance of characters in this crop some crosses have been made and this work is in progress. There was a complete success in crossing and no difficulty was experienced with the normal setting of the seeds under parchment paper bags.

### III. THE CLASSIFICATION AND DESCRIPTION OF TYPES.

#### 1. The morphological characters.

Thirty different types of *Sesamum* have been isolated. The chief morphological characters in which these types differ are (1) general habit, (2) colour of stem, (3) form and colour of the foliage, (4) flowers, (5) capsules, (6) seeds, and (7) period of growth, or maturity.

Duthie<sup>1</sup> describes the plant as follows :—

"An annual 3 to 4 feet high. *Stems* erect, branching, angular, striate, usually thickly clothed, especially the upper parts with short hairs. *Leaves* on long stalks, alternate or sub-opposite, crowded, very variable in shape, ovate, lanceolate tripartite or variously lobed, cuncate rounded or cordate at the base, upper usually linear lanceolate entire. *Flowers* solitary on short pedicels. *Calyx* 5 parted, segments lanceolate, acute, hairy. *Corolla* irregular, somewhat two lipped, lobes 5, broad, spreading, the lower one a little longer and forming a lip, pale yellow tinged with pink. *Stamens* 4 didynamous attached to the base of the corolla tube and included in it. *Ovary* 4 celled each carpel being divided by a spurious dissepiment, oblong, hairy, surrounded at the base by a small fleshy disc. *Ovules* axile, single row in each cell. *Capsule* 1-2 inches, oblong quadrangular, compressed, opening

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<sup>1</sup> Duthie and Fuller. Field and Garden Crops, Pt. II, page 35.

from above, loculicidally into 2 valves through the false dissepiments. *Seeds* numerous, compressed ovoid or obliquely oblong, lower and upper margins girt with a slender sharp ridge, black brown or white."

Excepting in one or two minor points, the above description generally holds good for all the types described in this paper.

According to Duthie "Flowers solitary and ovary 4 celled" but in this collection certain types having a few and fasciated forms of flowers and 6 to 8 loc ovary have also been isolated.

Hooker,<sup>1</sup> while describing "Flowers solitary or few and fasciated" does not mention about the 6 to 8 loc ovary.

*Habit.* The various types widely differ in height and in the extent and manner of branching. In some types, e.g., types 29, 30, the basal branches appear very low on the stem and the branches produce numerous laterals, thus the plants appear bushy. Whereas in other types, e.g., type 7, the secondary branches appear high up on the stem and do not form any laterals, the plants therefore look open in habit. Moreover certain types, particularly those with 3 flowers in the axil, e.g., type 3, have few or no branches.

The various habits of *Sesamum* plants are shown in Plate III.

*Stem.* The stem is usually erect, branching, angular and striate, and the upper part in particular is thickly covered with short hairs. Stems are either pale green or may have splashes of purple colour which is generally marked particularly towards the base.

*Leaves.* The various types differ considerably in shape, size, and colour of the foliage. In some types, e.g., types 4, 13, 20, the basal leaves are ovate to cordate and the upper leaves are lanceolate to linear; while in other types, e.g., types 1, 3, the basal leaves appear ovate to cordate but the leaves, immediately above them, become tripartite or variously lobed and the upper leaves are lanceolate and linear.

Among the types isolated, types 4, 13, 20, 22, are the only forms in which all the leaves are entire and none are divided. All the remaining types possess some divided leaves. This distinction is diagnostic of the types when they are well grown but it has been observed that the form of leaf to a certain extent also depends on the condition of growth. That is, if a plant accidentally remains undeveloped or in a juvenile state, the leaves retain the form of the basal type of leaf.

The lobes of the divided leaves also vary from a fairly small size, in types 19, 24, to the distinctly broad lobed leaves of types 2, 17. The margin of the leaf varies gradually from a serrate to the deeply dentate form of type 5. The surface of the leaf is generally glabrous, except in the case of type 25 which is thickly felted with short hairs. The colour of leaves ranges from a pale to a dark green colour.

*Petiole.* Petiole colour is practically the same as that of the stem.

*Flowers.* The flowers differ in size, colour and in the markings inside the tube. They are solitary or 2-3 together in a leaf axil, and always hairy.

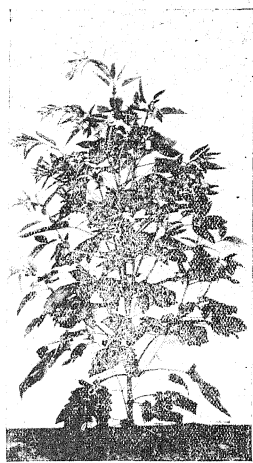
<sup>1</sup> Hooker. *Flora of British India*, Vol. IV, p. 387.



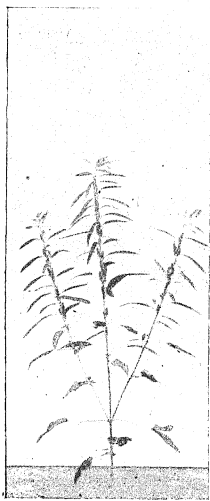
Type 29.



Type 30.



Type 17.



Type 7.

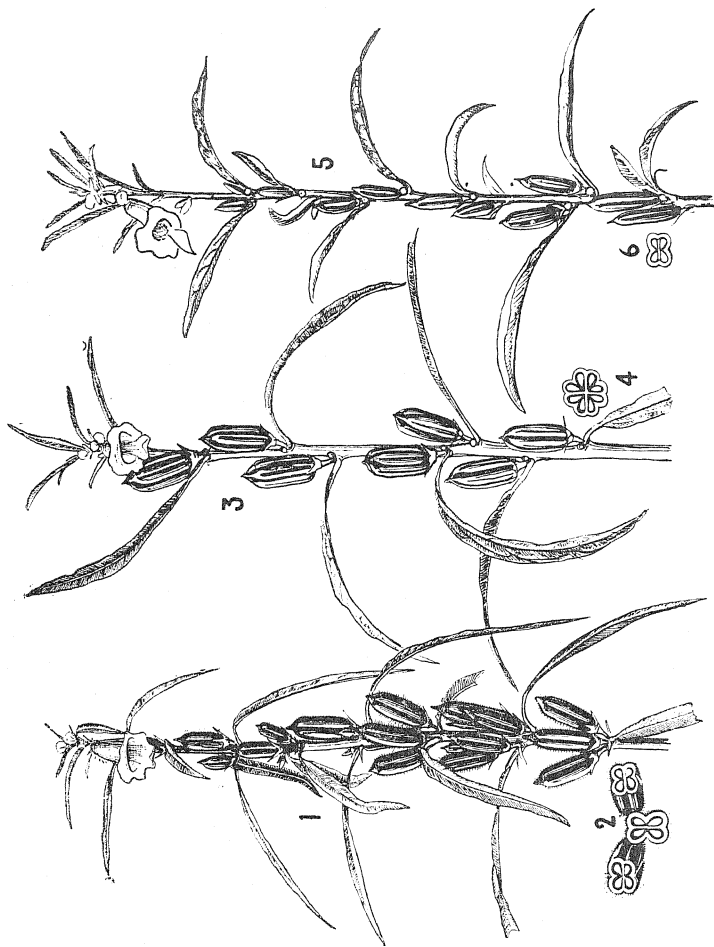


Type 12.

Sesamum types showing various habits of growth.



Type 3.



Type 1.

1. 3 capsules in the axil.

2. Cross sections of 4-lobed hairy capsules.

Type 4.

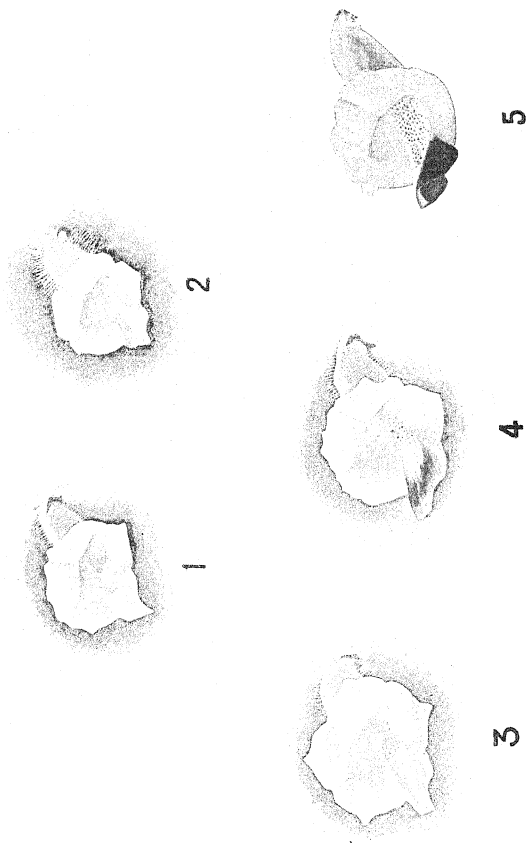
3. 8-lobed capsules.

4. Cross section of 8-lobed capsules.

Type 6.

5. 4-lobed capsules.

6. Cross section of 4-lobed smooth capsule.



The range in flower colour.

1, Very pale purple or almost white—Type 1; 2, White with a purple tinge—Type 16; 3, Light purple—Type 9; 4, Purple—Type 26; 5, Deep purple—Type 27.



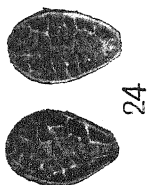
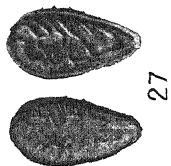
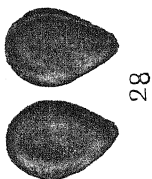
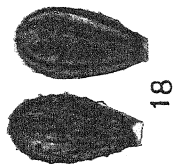
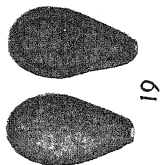
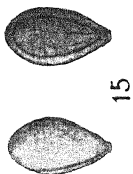
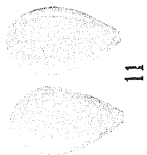
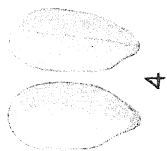
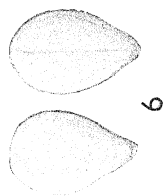


Type 28, purple coloured capsules.

## EXPLANATION OF PLATE VII.

### THE RANGE OF SEED COLOUR.

T. 6, 4—white smooth; T. 11, 13—dirty white smooth;  
T. 14—light brown rough; T. 15—brown smooth;  
T. 19—dark brown smooth; T. 18—dark brown rough;  
T. 20—olive grey smooth; T. 28—black smooth;  
T. 27, 24—black rough.





The general colour of the corolla is different shades of purple, as given below.

1. Very pale purple or almost white.
2. White with a purple tinge.
3. Light purple.
4. Purple.
5. Deep purple.

The corolla is gamopetalous forming a tube with a well marked yellow spot. The markings inside the tube are a series of purplish dots which are either few in number just below the yellow spot or a good many forming a patch extending down to the basal end of the lobe. The colour of the projecting lower lobe, excepting in some cases, is mostly the same as that of the corolla tube. Inside the corolla tube at a point where the anthers touch the lower lobe, there is a fine hairy growth. The number of these hairs and their length varies to a certain extent in different types.

The other details of the flower do not exhibit any perceptible differences among the various types.

The range of flower colour is shown in Plate V.

**Capsules.** The capsules vary much in shape, size, and in the number in the axil of a leaf. Invariably the capsules of all the types are hairy but in some cases the hairy growth is less prominent and the capsules look somewhat smooth.

The number of locules ranges from four to eight. Capsules of two carpels are primarily 2-loc. and become 4-loc. later by the growth of a false septum. Capsules, which are 8-loc., are similarly developed from four carpels by false septa.

The capsules are generally four loculed, but in types 4, 9, 11, 18, 20, they are eight loculed. The eight loculed capsules are always invariably borne singly in each leaf axil. The four loculed ones occur either singly or in groups of 2-3 in the axil.

These two characters are not always constant as sometimes a plant having most of its capsules 8-loculed may also possess one or two 4-loculed or even 6-loculed capsules; and a plant having three capsules in the axis may also bear only one or two capsules in an axil.

Type 28 possesses purple coloured capsules, it therefore stands out from all the other *Sesamum* types.

The different forms of capsules are shown in Plates IV and VI.

**Seeds.** The seeds vary considerably in colour and size and in the surface of the seed-coat. The colour ranges from pure white, through various shades of brown and grey to black. The size of the seed is either small, medium or bold (large) and the seed-coat is either rough or smooth.

The range of seed colour is shown in Plate VII.

**Maturity.** There is a great deal of difference in the length of the growth period and date of maturity in different types and types can be classified into early, medium, and late types.

*Statement showing the maturity of different types.*

EARLY	MEDIUM	LATE
3 to 4 weeks after sowing	5 weeks after sowing	6 to 8 weeks after sowing
Types	Types	Types
1, 3, 4, 6, 7, 8, 9, 11, 13, 14, 15, 19, 20, 22, 23, 24.	2, 10, 12, 16, 18, 21, 26, 27.	5, 17, 25, 28, 29, 30.

The above statement is based on the dates of the first flower on the plant.

Vegetative characters of habit, stem and leaf are liable to fluctuating variation under varying conditions of the environment, and the characters of the flower, fruit, seed and maturity furnish the most reliable criteria for classifying the types. The classification of types was, therefore, based on flower, fruit, seed and maturity.

*2. Key\* to the Types of Sesamum indicum Linn.***Flowers 2 to 3 in the axil.**

Seeds white, smooth.

Corolla almost white.

Corolla hairs short.

Markings nil.

Plants early . . . . . Type 1.

Corolla light purple.

Corolla hairs medium.

Markings very few.

Plants medium in maturity . . . . . Type 2.

Corolla hairs long.

Markings many.

Plants early . . . . . Type 3.

**Flowers solitary.**

Seeds white, smooth.

Corolla light purple.

Corolla hairs short.

Markings many.

Capsule 8-loculed.

Plants very early . . . . . Type 4.

Corolla hairs medium.

Markings many

Plants late . . . . . Type 5.

Plants early . . . . . Type 6.

Corolla hairs long.

Markings many.

Plants early . . . . . Type 7.

\* Unless otherwise stated the capsule is four loc.

2. *Key\* to the Types of Sesamum indicum Linn—contd.*

Flowers solitary.

Seeds dirty white, smooth.

Corolla white with a purple tinge.

Corolla hairs long.

Markings few.

Plants early . . . . . Type 8.

Corolla light purple.

Corolla hairs medium.

Markings many.

Capsule 8-loculed.

Plants early . . . . . Type 9.

Corolla hairs long.

Markings many.

Plants medium in maturity . . . . . Type 10.

Corolla hairs short.

Markings few.

Capsule 8-loculed.

Plants medium in maturity . . . . . Type 11.

Corolla purple.

Corolla hairs short.

Markings many.

Plants early . . . . . Type 12.

Corolla hairs very long.

Markings very many.

Plants early . . . . . Type 13.

Seeds light brown, surface rough.

Corolla light purple.

Corolla hairs medium.

Markings nil.

Plants very early . . . . . Type 14.

Seeds brown, smooth.

Corolla almost white.

Corolla hairs short.

Markings nil.

Plants early . . . . . Type 15.

Corolla white with a purple tinge.

Corolla hairs long.

Markings many.

Plants medium in maturity . . . . . Type 16.

Corolla light purple.

Corolla hairs medium.

Markings many.

Plants late . . . . . Type 17.

Seeds dark brown, surface rough.

Corolla light purple.

Corolla hairs medium.

Markings nil.

Capsule 8-loculed.

Plants medium in maturity . . . . . Type 18.

Seeds dark brown, surface smooth.

Corolla light purple.

Corolla hairs short.

Markings very few.

Plants very early . . . . . Type 19.

\* Unless otherwise stated the capsule is four loc.

2. Key\* to the Types of *Sesamum indicum* Linn.—*contd.*Flowers solitary—*contd.*

Seeds olive grey, smooth.

Corolla white with a purple tinge.

Corolla hairs short.

Markings few.

Capsule 8-lobed.

Plants very early . . . . . Type 20.

Corolla purple.

Corolla hairs short.

Markings very few.

Plants medium in maturity . . . . . Type 21.

Seeds smoke grey, smooth.

Corolla light purple.

Corolla hairs long.

Markings many.

Plants early . . . . . Type 22.

Corolla purple.

Corolla hairs long.

Markings many.

Plants early . . . . . Type 23.

Seeds black, surface rough.

Corolla white with a purple tinge.

Corolla hairs short.

Markings nil.

Plants early . . . . . Type 24.

Corolla light purple.

Corolla hairs medium.

Markings many.

Plants late . . . . . Type 25.

Corolla purple.

Corolla hairs long.

Markings many.

Plants medium in maturity . . . . . Type 26.

Corolla deep purple.

Corolla hairs long.

Markings enormous.

Plants medium in maturity . . . . . Type 27.

Seeds black, surface smooth.

Corolla light purple.

Corolla hairs long.

Markings few.

Capsule purple.

Plants late . . . . . Type 28.

Markings many.

Plants late . . . . . Type 29.

Corolla purple.

Corolla hairs short.

Markings many.

Plants late . . . . . Type 30.

\* Unless otherwise stated the capsule is four loc.

### 3. *Description of the types.*

Type 1. Plants early, dwarf, rather compact, branches few; stem pale green; leaves divided, lobes small, colour dark green; petiole pale purple; flowers 2-3 in the axil; corolla medium, almost white, hairy, hairs short, lower lobe almost white, markings practically nil; capsule 4-loculed, medium, hairy; seeds small, white, smooth.

Type 2. Plants medium in maturity, tall, branches few; stem with purple splashes and not very strong; leaves divided, lobes broad, colour dark green; petiole purplish; flowers 2-3 in the axil, medium, light purple, hairy, hairs medium, lower lobe purple, markings very few; capsule 4-loculed, medium, smooth; seeds bold, white, smooth.

Type 3. Plants early, height medium, branches practically nil; stem with purple splashes, rather weak and susceptible to stem-rot if rains are heavy; leaves divided, lobes medium, colour dark green; petiole purplish; flowers 2-3 in the axil, big, light purple, hairy, hairs long, lower lobe light purple, markings many and all round inside the corolla tube; capsule 4-loculed, medium, hairy; seeds medium, white, smooth.

Type 4. Plants very early, height medium, branches very few; stem pale green and rather weak; leaves all simple, ovate, colour dark green; petiole pale green; flower one in the axil, medium, light purple, hairy, hairs short, lower lobe light purple, markings many and all round inside the corolla tube; capsule 6-8-loculed, small, smooth; seeds rather long, white, smooth.

Type 5. Plants late, height medium, somewhat open and moderately branched, branches start low on the stem and give off some laterals; stem with purple splashes; leaves divided, lobes medium and deeply dentate, colour light green; petiole purplish; flower 1 in the axil, small, light purple, hairy, hairs medium, lower lobe light purple, markings many and all round inside the corolla tube; capsule 4-loculed, medium, hairy; seeds small, white, smooth.

Type 6. Plants early, height medium, very open, sparsely branched, branches start low on the stem; stem pale green; leaves divided, lobes small, colour dark green; petiole pale green; flower 1 in the axil, medium, light purple, hairy, hairs medium, lower lobe light purple, markings many and all round inside the corolla tube; capsule 4-loculed, medium, smooth; seeds medium, white, smooth.

Type 7. Plants early, height medium, open, sparsely branched; stem with purple splashes, rather weak and susceptible to stem-rot if rains are heavy; leaves divided, lobes small, colour somewhat dark green; petiole purplish; flower 1 in the axil, medium, light purple, hairy, hairs long, lower lobe light purple, markings many and all round inside the corolla tube; capsule 4-loculed, medium, hairy; seeds medium, white, smooth.

Type 8. Plants early, height medium, open, moderately branched, branches start low on the stem and give off few laterals; stem with purple splashes and rather weak; leaves divided, lobes medium, colour dark green; petiole purplish; flower 1

in the axil, big, white with a purplish tinge, hairy, hairs long, lower lobe very pale purple, markings few; capsule 4-loculed, medium, hairy; seeds medium, dirty white, smooth.

Type 9. Plants early, height medium, open, moderately branched, branches start low on the stem; stem with purple splashes; leaves divided, lobes medium, colour somewhat dark green; petiole purplish; flower 1 in the axil, big, light purple, hairy, hairs medium, lower lobe light purple, markings many and all round inside the corolla tube; capsule 4-8-loculed, medium, hairy; seeds medium, dirty white, smooth.

Type 10. Plants medium in maturity, tall, bushy, profusely branched, branches give off many laterals; stem with purple splashes; leaves divided, lobes medium, colour dark green; petiole purple; flower 1 in the axil, medium, light purple, hairy, hairs long, lower lobe light purple, markings many and all round inside the corolla tube; capsule 4-loculed, medium, hairy; seeds medium, dirty white, smooth.

Type 11. Plants medium in maturity, tall, somewhat spreading, moderately branched, branching starts rather high on the stem; stem with purple splashes; leaves divided, lobes medium, colour somewhat dark green; petiole purple; flower 1 in the axil, big, light purple, hairy, hairs short, lower lobe light purple, markings few; capsule 4-8-loculed, small, smooth; seeds medium, dirty white, smooth.

Type 12. Plants early, height medium, moderately branched; stem purple, weak and susceptible to stem-rot if rains are heavy; leaves divided, lobes small, colour light green; petiole purple; flower 1 in the axil, very big, purple, hairy, hairs short, lower lobe purple, markings many and all round inside the corolla tube; capsule 4-loculed, very long, twisted, smooth; seeds medium, dirty white, smooth.

Type 13. Plants early, height medium, branches nil; stem purple, rather weak and susceptible to stem-rot if rains are heavy; leaves all simple, broad, ovate, colour dark green; petiole purple; flower 1 in the axil, very big, purple, hairy, hairs very long, lower lobe purple, markings very many and all round inside the corolla tube; capsule 4-loculed, big, hairy; seeds medium, dirty white, smooth.

Type 14. Plants very early, dwarf, sparsely branched; stem with purple splashes; leaves divided, lobes small, colour light green; petiole purplish; flower 1 in the axil, medium, light purple, hairy, hairs medium, lower lobe light purple; markings nil; capsule 4-loculed, medium, smooth; seeds medium, light brown, rough.

Type 15. Plants early, height medium, open, moderately branched; stem pale green; leaves divided, lobes small, colour light green; petiole pale green; flower 1 in the axil, medium, almost white, hairy, hairs short, lower lobe very pale purple, markings few or practically nil; capsule 4-loculed, medium, smooth; seeds small, brown, smooth.

Type 16. Plants medium in maturity, height medium, open, sparsely branched; stem with purple splashes; leaves divided, lobes small, colour somewhat dark green;

petiole purple ; flower 1 in the axil, medium, white with a purple tinge, hairy, hairs rather long, lower lobe purple, markings many and all round inside the corolla tube ; capsule 4-loculed, small, smooth ; seeds medium, brown, smooth.

Type 17. Plants late, tall, bushy, profusely branched, branches start low on the stem and give off some laterals ; stem purple ; leaves divided, lobes very broad, colour dark green ; petiole purple ; flower 1 in the axil, medium, light purple, hairy, hairs medium ; lower lobe deep purple, markings many and all round inside the corolla tube ; capsule 4-loculed, medium, smooth ; seeds medium, brown, smooth.

Type 18. Plants medium in maturity, height medium, open, moderately branched ; stem with purple splashes ; leaves divided, lobes medium, colour somewhat light green ; petiole light purple ; flower 1 in the axil, big, light purple, hairy, hairs medium, lower lobe purple, markings nil ; capsule 6-8-loculed, small, smooth ; seeds medium, dark brown, rough.

Type 19. Plants very early, very dwarf, branches few ; stem with purple splashes ; leaves divided, lobes small, colour light green ; petiole purple ; flower 1 in the axil, small, light purple, hairy, hairs short, lower lobe light purple, markings very few ; capsule 4-loculed, medium, smooth ; seeds medium, dark brown, smooth.

Type 20. Plants very early, height medium, branches very few ; stem with purple splashes and weak ; leaves all simple, ovate, colour light green ; petiole purplish ; flower 1 in the axil, medium, white with a purple tinge, hairy, hairs short, lower lobe very pale purple, markings few ; capsule 8-loculed, small, smooth ; seeds medium, olive grey, smooth.

Type 21. Plants medium in maturity, height medium, open, moderately branched, branches start high on the stem ; stem with purple splashes ; leaves divided, lobes medium, colour light green ; petiole purplish ; flower 1 in the axil, medium, purple, hairy, hairs short, lower lobe light purple, markings very few ; capsule 4-loculed, small, smooth ; seeds olive grey, smooth.

Type 22. Plants early, height medium, open, moderately branched, branches give off some laterals ; stem with purple splashes and rather weak ; leaves all simple, ovate, colour light green ; petiole purplish ; flower 1 in the axil, big, light purple, hairy, hairs long, lower lobe light purple, markings many and all round inside the corolla tube ; capsule 4-loculed, medium, hairy ; seeds medium, smoke grey, smooth.

Type 23. Plants early, tall, sparsely branched ; stem with purple splashes, rather weak and susceptible to stem-rot if rains are heavy ; leaves divided, lobes medium, colour dark green ; petiole purplish ; flower 1 in the axil, big, purple, hairy, hairs long, lower lobe purple, markings many and all round inside the corolla tube ; capsule 4-loculed, medium, hairy ; seeds bold, smoke grey, smooth.

Type 24. Plants early, height medium, open, moderately branched, branches give off some laterals ; stem with purple splashes ; leaves divided, lobes small, colour light green ; petiole purplish ; flower 1 in the axil, big, white with a purple tinge,

hairy, hairs short, lower lobe very pale purple, markings very few or practically nil ; capsule 4-loculed, medium, smooth ; seeds medium, black, rough.

Type 25. Plants late, height medium, bushy, profusely branched, branches start low on the stem and produce some laterals ; stem pale green ; leaves divided, lobes medium, colour dark green, felted with short hairs ; petiole greenish ; flower 1 in the axil, small, light purple, hairy, hairs medium, lower lobe light purple, markings many and all round inside the corolla tube ; capsule 4-loculed, medium, hairy ; seeds small, black, rough.

Type 26. Plants medium in maturity, tall, bushy, profusely branched, branches start low on the stem and also produce few laterals ; stem with purple splashes ; leaves divided, lobes medium, colour light green ; petiole purplish ; flower 1 in the axil, medium, purple, hairy, hairs rather long, lower lobe deep purple, markings many and all round inside the corolla tube ; capsule 4-loculed, small, hairy ; seeds medium, black, rough.

Type 27. Plants medium in maturity, tall, bushy, profusely branched, branches start low on the stem and also produce many laterals ; stem with purple splashes ; leaves divided, lobes small, colour dark green ; petiole purplish ; flower 1 in the axil, medium, deep purple, hairy, hairs long, lower lobe very deep purple, markings enormous and all round inside the corolla tube ; the anthers are marked with black longitudinal lines ; capsule 4-loculed, medium, somewhat smooth ; seeds rather long, black, rough.

Type 28. Plants late, tall, bushy, profusely branched, branches start low on the stem and also produce many laterals ; stem with purple splashes ; leaves divided, lobes rather medium, colour dark green ; petiole purple ; flower 1 in the axil, medium, light purple, hairy, hairs long, lower lobe purple, markings few ; capsule 4-loculed, small, hairy, purple coloured ; seeds medium, black, smooth.

Type 29. Plants late, height medium, bushy, profusely branched, branches start very low on the stem and also produce many laterals ; stem with purple splashes ; leaves divided, lobes medium, colour dark green ; petiole purplish ; flower 1 in the axil, medium, light purple, hairy, hairs long, lower lobe deep purple, markings many ; capsule 4-loculed, small, hairy ; seeds medium, black, smooth.

Type 30. Plants late, tall, bushy, profusely branched, branches start low on the stem and also produce many laterals ; stem with purple splashes ; leaves divided, lobes broad, colour dark green ; petiole purple ; flower 1 in the axil, big, purple, hairy, hairs short, lower lobe deep purple, markings many and all round inside the corolla tube ; capsule 4-loculed, small, smooth ; seeds medium, black, smooth.

#### IV. SEPALOID-FORM.

The corolla may become modified into sepals and the internal structure of the flower become abnormal, throwing out a leafy growth which does not produce any

seed. Sometimes only a part of the plant changes into a sepaloid form (Text Fig. 1)



Text-fig. 1.

- (a) Corolla modified into sepals.
- (b) Longitudinal section showing the abnormal internal structure of a sepaloid corolla.
- (c) Sepaloid corolla throwing a leafy growth.

but, even so, few of the branches bear normal flowers and produce viable seeds. In order to find out if sepaloidy was a character hereditary in some types, a small quantity of seeds from a partially sepaloid plant was preserved and sown in the following season. The plants produced from such seeds were quite normal and did not show even a small percentage of any such character. It was also believed that the continuous bagging of a plant for a number of years might be one of the causes of bringing this sepaloid condition in *Sesamum*, but the facts do not prove the same. In the year 1924-25, when the samples of seeds were collected from all over the country, it was certain that the seeds so received were from unbagged plants and there was a high percentage of sepaloid forms among the plants grown from these

seeds. In the course of our observations it has been experienced that early sowing, if accompanied with a heavy rainfall, greatly favours the sepaloidy.

TABLE VI.

*Rainfall and the percentage of sepaloid plants.*

Sowing time	INCHES OF RAINFALL DURING THE GROWING PERIOD				Total rainfall	Percentage of sepaloid plants in late types
	July	August	September	October		
13th July 1925 . .	6.64	15.78	16.38	0.17	38.97	8 per cent.
1st July 1926 . .	16.48	11.32	5.75	0.06	33.61	13 per cent.
15th August 1927 . .	..	1.41	4.71	0.26	6.38	Practically nil
16th August 1928 . .	..	5.12	2.52	6.21	13.85	Practically nil

From the foregoing Table, it appears that the change from the normal condition to the sepaloid form to a certain extent may be due to a disturbance of the physiological conditions of the plant induced by early sowings accompanied with heavy rainfall.

#### V. ECONOMIC ASPECT.

From an economic point of view, *Sesamum* can be favourably compared with the olive of the Mediterranean. There are at least three easily recognised forms, white, black and brown. The value of the seeds partly depends on their oil content. Therefore the determination of the percentage of oil in some of the types grown at Pusa was made and the results are given below.

TABLE VII.  
Oil content, size, colour and seed-coat.

Type No.	Size, colour and seed-coat	Percentage of oil*
3	Small, white, surface smooth . . . . .	48.33
4	" " " " . . . . .	49.10
6	" " " " . . . . .	49.14
10	Medium " " " " . . . . .	49.09
13	" dirty white, surface smooth . . . . .	47.39
22	" " " " " " . . . . .	49.00
23	" grey " " . . . . .	49.25
21	" " " " " " . . . . .	46.91
29	" black " " . . . . .	47.11
16	" dark brown " " . . . . .	51.60
27	" black " rough . . . . .	41.52
18	" dark brown " " . . . . .	37.88

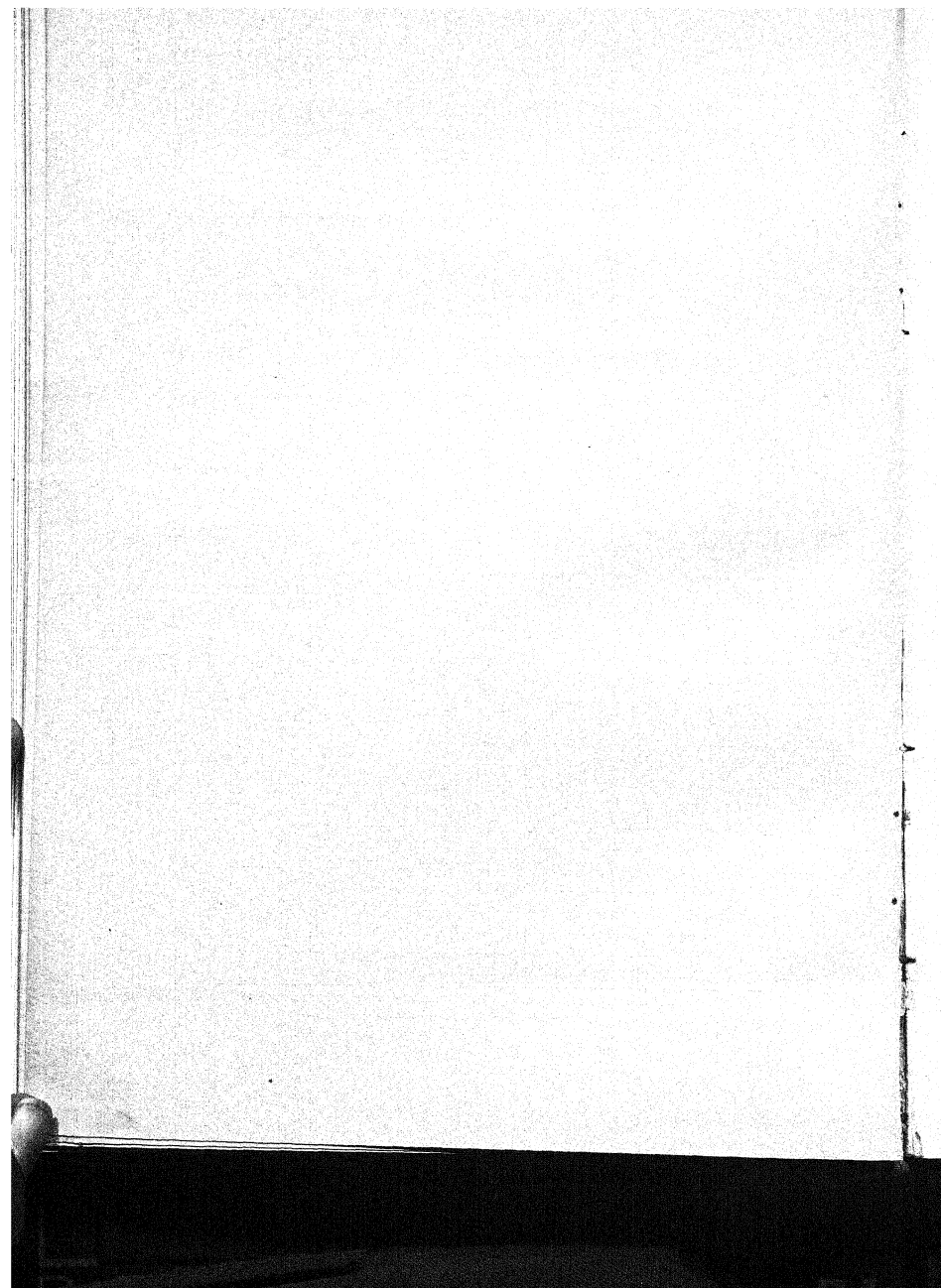
It appears from the above Table that there is a definite correlation between a rough surface of the seed and a lower percentage of oil. Most probably this is due to the greater percentage of husk in the rough seeded varieties.

The economic value of the variety depends not only on the percentage of oil in the seed but also to a large extent on the yields of seed obtained per acre. The black seeded varieties which possess a greater power of branching are the higher yielders, although the white seeded varieties yield a better and clearer oil which fetches a little higher price on the market.

The oil is extracted by expression in mills. It varies in colour from pale yellow to dark amber. It has no smell and is not liable to become rancid. In India it is largely used for culinary purposes, in anointing the body, and in soap manufacture. It is also frequently applied as an adulterant of *ghi*. The oil from the black variety is generally stated to be more suitable for medicinal purposes than that from the white. It is also extensively employed in the manufacture of Indian perfumes, and for this purpose the oil is frequently extracted from the seeds after the latter have been impregnated with a perfume. The white seeded variety is largely eaten as an article of food, more especially in certain sweetmeats.

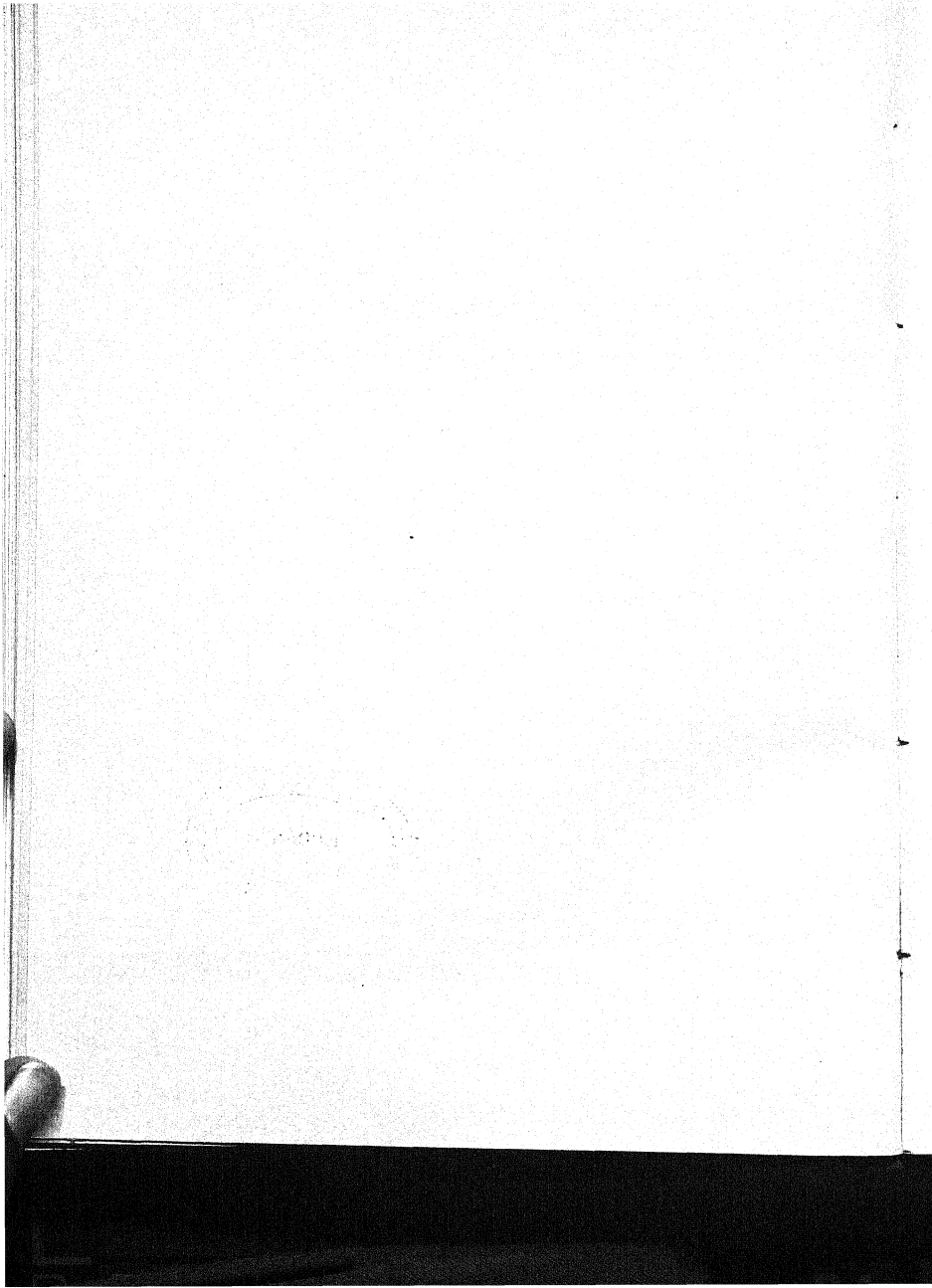
The oil cake is used as a cattle food and as a manure, in this latter respect *Sesamum* cake is inferior to castor or mustard cake.

\* These determinations were carried out by the Imperial Agricultural Chemist, Pusa.



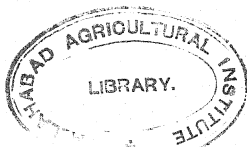
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# CLASSIFICATION, AND STUDY OF CHARACTERS, OF THE CULTIVATED RICES IN THE UNITED PROVINCES.

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## I. INTRODUCTION.

The work of classifying the rices of the United Provinces has been in progress during the last six years (1923-28). This paper is a summary of the work up to date. The number of varieties of the rices grown in these Provinces is large and widely differing in character. About one thousand samples were collected from all over the Province by the departmental subordinates and through the kindness of District Officers, and were sown on the Botanical Research Farm, Cawnpore, in 1923. It was found on their growth that the majority of the samples were mixtures of various types and also in many cases the same varieties were sent under different names from different districts. From this bulk, duplicates were sorted out and single well-grown plants, numbering 415, exhibiting the characters of a particular variety, were selected and a minute description of each was taken. Single ears of well-growing plants were again selected from these strains for two successive years when their characters were compared and all doubtful duplicates and the plants showing splitting of characters, as probable crosses, were rejected. This pure line selection has been continued for six years, till 135 types have been isolated as pure strains possessing constant characters. It is these varieties which have been classified and a description of their characters, which have been studied during the course of these six years, has been given in detail. It may be mentioned that the

vernacular names, under which these original samples referred to above were sent from various districts, were very confusing. In many cases the same vernacular name is often applied to totally different varieties in different districts, while, on the other hand, more commonly, different names are given to the same variety in different parts of the Province, e.g., the names of *bansmati* and *hansraj*, being fine and famous rices of the United Provinces, are commonly applied to a fine kind of a district all over the Province, and the same rice is called *latera* in the district of Unao and *Anjee* in Basti district or *gullballia* of Allahabad is the same as *ram-latha* of Sultaupur. Thus the vernacular name is no guide to the identification of a rice.

## II. HISTORY OF PREVIOUS WORK ON CLASSIFICATION.

Several scientists have hitherto tried to classify the rices. Amongst the older authors we may mention the names of Roxburg, Duthie, Watt and Hooker. The classifications of these authors are very simple and are by no means comprehensive. Roxburg<sup>1</sup> (1874) divides the numerous varieties of *Oryza sativa* L. into two orders, the first the *Poonas* or the early sorts, the second the *Pedda* and *Warloo* or *Pedupanta* which means the late or great crop. He has further grouped eight sorts under the first and about twenty-nine in the second. Duthie and Fuller<sup>2</sup> (1882), while classifying the rices of the United Provinces, group the varieties into three classes, the first including those with tall habit of growth, with the ear protruded from the sheath, feathery and drooping and with thin usually yellow-husked grain, the second including varieties with a shorter habit of growth and shorter stems with the ear not so prominent and carried more erect than that of the preceding and with thick yellow or red-husked grain and the third comprising the common varieties of paddy with short strong stems, ear partially enclosed in the sheath and grain-husk dark-coloured or black. According to them the varieties of the first class are most highly prized, the commonest being those known as *bansmati*, *bansphool* and *ghilma*, the *seondhi* and *sumhara* are the principal varieties of the second class, while *sathi* (so called from its growth covering sixty days) is by far the most important of those included in the third class. Duthie has also another simpler method of classification and groups the varieties according to the method of their cultivation, as first those transplanted from seed beds and second those sown broadcast. According to him, as a general rule, the fine varieties falling under the first two classes above named are raised in seed-beds, and planted out, while the coarser kinds are sown in the field broadcast. Watt<sup>3</sup> (1891) divides the

<sup>1</sup> Roxburg. *Flora Indica*, p. 306.

<sup>2</sup> Duthie, and Fuller. *Field and Garden crops*, pp. 15, 1882.

<sup>3</sup> Watt, Sir J. *Dictionary of Economic products*, Vol. V, pp. 504-506.

wild rices into four varieties viz., *rufipogon*, *coarctata*, *bengalensis* and *abuensis* but in dealing with the cultivated rices he classifies them first according to the localities and then sub-divides the groups according to the season of the cultivation. Hooker <sup>1</sup> (1897) divides the tribe *Oryza* L. simply into five main groups.

In later years, Gammie<sup>2</sup> (1908) divided the Bombay rices into fifteen varieties based on the character of the ear, number of the primary branches on it and the shape and the colour of the spikelets. Kikwa<sup>3</sup> (1912), a Japanese botanist, classified the rices of Burma, taking into consideration the characters of the grain. He gives two schemes of classification. The first divides rices according to their agricultural characters and the second by the characters of the grain. He uses only the second method in classifying Burmese rices. His classification is much more reasonable than those of others. Graham<sup>4</sup> (1913) classified the rices of the Central Provinces and employed the character of the colours of the leaf-sheath as the main heads of his classification.

Further Beale<sup>5</sup> in 1927 and Thadani<sup>6</sup> in 1928 contributed to this part of the systematic work by classifying rices in Burma and Sindh, respectively. The former gives only the broad schemes of classification without going into details, and the latter employs, like others, the agricultural and colour characters for classifying the Sindh varieties. Thus no detailed classification of rices of any Province based on the characters of the size and shape of the grain is available in India.

While handling a fairly large number of rice varieties in the United Provinces and noticing that the subject had not been studied before from a systematic point of view in these provinces, the necessity for a scheme of classification became apparent. The writer has more or less followed Kikwa's system in classifying the rices of these Provinces as, besides being most useful economically, the characters of the grains are more constant than either agricultural or vegetative characters. Before giving the scheme of classification and the grouping of varieties according to that scheme, it would be advisable to describe the various characters of the rice plant and discuss their relative merits. These may be divided into two classes, i.e., vegetative and reproductive. These characters have been observed in Pedigree cultures for more than three successive generations, and may therefore be safely taken as the expression of hereditary qualities of the various cultures.

<sup>1</sup> Hooker. *Flora of British India*, Vol. VII, p. 92.

<sup>2</sup> Gammie, G. A. *Dep't. Agri. Bombay, Bull.*, No.30, 1908, p. 89.

<sup>3</sup> Kikwa, S. On the classification of cultivated rice. *Jour. College Agri. Imperial University, Tokyo*, Vol. III, No. 2.

<sup>4</sup> Graham, R. J. D. Preliminary note on the classification of rice in the Central Provinces. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. VI, p. 209, 1913.

<sup>5</sup> Beale, R. A. A scheme of classification of the varieties of rice found in Burma. *Agri. Res. Inst. Pusa Bull.* 167, 1927.

<sup>6</sup> Thadani, K. I., and Durga Dutt. Studies on rice in Sindh, part I. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. XV, No. 6, 1928.

## III. VEGETATIVE CHARACTERS.

1. *Germination and early growth.*

The time taken for germination by the various strain in the nursery was studied in order to see the difference in germination between early and late and fine and coarse-grained types. The results are shown in Tables I and II :—

TABLE I.

*Showing difference in germination between early and late maturing types (sown on 6th June 1927).*

Nature of strain	Total No. of types sown	GERMINATION AFTER SOWING							
		4th day		5th day		6th day		7th day	
		No. of types germinated	Percentage	No. of types germinated	Percentage	No. of types germinated	Percentage	No. of types germinated	Percentage
Early .	48	24	50	21	43.75	3	6.25	0	0
Medium .	8	4	50	2	25	2	25	0	0
Late .	55	15	27.3	26	47.3	8	14.5	6	10.9
Very late .	11	2	18.2	3	27.3	4	36.3	2	18.2

A majority of the early-ripening types are more vigorous in their germination than the late-ripening types. The former as well as the medium class germinate within six days after sowing, while a fair percentage of the late group continue germinating till the 7th day.

TABLE II.

*Showing difference in germination between coarse and fine shaped grains (1927).*

Nature of grain	Total No. of types sown	GERMINATION AFTER SOWING							
		4th day		5th day		6th day		7th day	
		No. of types germinated	Percentage	No. of types germinated	Percentage	No. of types germinated	Percentage	No. of types germinated	Percentage
Coarse .	42	10	45.2	21	50	1	2.4	1	2.4
Medium .	36	17	47.2	14	38.8	3	8.4	2	5.6
Fine .	32	8	25	11	34.4	9	28.1	4	12.5
Round .	12	1	8.3	6	50	4	33.4	1	8.3

A majority of coarse and medium-grained types germinate within five days after sowing, while a fair percentage of fine types take as many as six and even seven days to germinate. Round types behave more or less like fine-grained ones. It is obvious from the above Tables that, though a majority of fine and late varieties are not so vigorous in their germination as the coarse and early types, it is not invariably so in all the cases. Some fine and late strains do germinate as quickly as early and coarse ones and *vice versa*.

The maximum temperature in shade in June at the time of germination varied from 104° to 110° F. Later on in the season, however, from July to September when the maximum temperature varied from 91° to 99° F., it took longer time to germinate. The character of the time of germination is thus variable and is influenced by the temperature of the season. Moreover the difference in time of germination and early growth of various types is not an important feature as to be employed as a basis in the scheme of classification. The behaviour, however, of the various strains, later in growth, or in being transplanted in the field after the seedling stage show some differences in the number of tillers, leaves and the height of the plant. These are discussed under their respective heads.

## 2. Tillering capacity.

Tillering in the rice plant commences a fortnight after transplanting and continues till the emergence of the ear. The character is of considerable economic importance as it is closely connected with the yield. Generally speaking, early strains are poor, while the late ones are rich in tillering, but late-maturity and high-tillering are not necessarily correlated in all the varieties (Table III).

TABLE III.

*Showing average total number of tillers in different strains.*

Strain No.	Number of days required from sowing (in broadcast) or transplanting to maturity	Mean number of tillers
<i>Broadcast—</i>		
132 . . . . .	71	
133 . . . . .	75	
125 . . . . .	94	11.8
123 . . . . .	98	9

Each figure represents average of twenty countings. Spacing between plants was 1 × 1 foot.

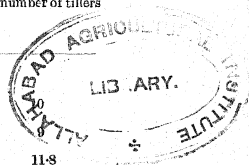


TABLE III—*contd.**Showing average total number of tillers in different strains—contd.*

Strain No.	Number of days required from sowing (in broadcast) or transplanting to maturity,	Mean number of tillers.
<i>Transplanted early—</i>		
12 . . . . .	78	19
65 . . . . .	78	14.5
124 . . . . .	76	18.9
71 . . . . .	80	13.8
48 . . . . .	80	21.5
63 . . . . .	76	24.6
<i>Medium—</i>		
31 . . . . .	85	21.4
126 . . . . .	85	19.6
43 . . . . .	88	13.8
3 . . . . .	86	23.8
85 . . . . .	102	26.4
<i>Late—</i>		
66 . . . . .	127	19
62 . . . . .	127	36.4
116 . . . . .	129	14.3
98 . . . . .	133	31.6
125 . . . . .	133	36.6
99 . . . . .	133	28
94 . . . . .	120	11.1
115 . . . . .	131	24.4

Each figure represents average of twenty countings. Spacing between plants was 1×1 foot.

Tillers appearing late in life do not produce panicles. The percentage of these sterile tillers varies in different strains and is an objectionable feature. The rate of growth of tillers was studied in a few strains and it was found that early varieties attain their maximum sooner than the late varieties, more especially in the transplanted series (Table IV).

TABLE IV.

*Showing the rate of growth as indicated by the average number of tillers per plant at successive one week periods.*

Periods 1928	SOWN BROADCAST (12TH JULY)		TRANSPLANTED (SOWN IN NURSERY ON 6TH JUNE AND TRANSPLANTED ON 12TH JULY)		
	Strains				
	Early No. 132	Late No. 128	Early No. 7	Medium No. 21	Late No. 25
August 1 . . .	1	2	11	6.2	7.7
„ 8 . . .	1.5	3.5	16.5	9.5	11.7
„ 15 . . .	3.1	9	23.7	15.9	19.2
„ 22 . . .	5.1	10.5	26.8	19.4	27.6
„ 29 . . .	8.2	11	27.1	20.1	28.3
September 5 . . .	9.7	12.6	..	20.2	30.7
„ 12 . . .	..	12.8	..	..	30.8
„ 19 . . .	..	..	..	..	30.9
„ 26 . . .	..	..	..	..	31.5

The figures are shown up to their maximum limits and each figure is the average of twenty counts. Spacing between plants was 1×1 foot.

While the relative number of tillers is a feature which is characteristic of varieties, the amount of tillering varies in different years, so far as the cultivated

varieties are concerned, probably owing to variations in the manner of water supply, the land on which they are grown, and spacing between plants (Table V).

TABLE V.

*Variations in tillering as affected by spacing between plants.*

Distances (inches apart)	Strain No. 65 (early)	Strain No. 99 (late)
	Average No. of tillers per plant	Average No. of tillers per plant
3×3 . . . . .	4.3	12.9
6×6 . . . . .	8.6	16.7
9×9 . . . . .	11.0	20.2
12×12 . . . . .	14.8	29.0

Each figure is an average counting of 50 plants.

The character is thus very variable and is not useful from a classification point of view.

### 3. Leaf.

The lamina is usually green in colour and the mid-rib yellow or light yellow but in types possessing deep coloured leaf-sheaths, the mid-rib is also of purple colour. In one variety (No. 94), the whole leaf is of deep purple colour. This is a very useful distinguishing character, but it is present only in one type in the United Provinces. The flag or the uppermost leaf is often a good index of the size of the leaves of the plant in general. It is generally the broadest of all the leaves. It may assume an erect, horizontal or downward inclined position. An erect position usually signifies a strong stem of the plant. The leaves are also covered by hairs on both sides. These are more abundant on coarse thick leaves than on thin fine leaves. The former are generally found in coarse-grained varieties, and the latter in fine-grained types. Like tillers there is also a variation in the development of leaves in early and late kinds. This is shown in Table VI.

TABLE VI.

Showing the rate of growth as indicated by the average number of leaves per plant at successive one week periods.

Periods 1928		SOWN BROADCAST (12TH JULY)		TRANSPLANTED (SOWN IN NURSERY ON 6TH JUNE AND TRANSPLANTED ON 12TH JULY)		
		Strains				
		Early No. 132	Late No. 128	Early No. 7	Medium No. 21	Late No. 25
August	1 . . .	4.0	6	31	16.8	22.2
"	8 . . .	5.5	10	47.9	28.6	34.8
"	15 . . .	8.7	25.5	77.1	49.4	61.3
"	22 . . .	13.9	53	107.7	70	97.8
"	29 . . .	14.3	68	123.1	84.8	120.2
September	5 . . .	15.4	97.5	..	93.4	144.4
"	12 . . .	..	107.5	..	..	146
"	19 . . .	..	..	..	..	146.6
"	26 . . .	..	..	..	..	146.6
October	3 . . .	..	..	..	..	149.3

The figures are shown up to their maximum limits and each figure is the average of twenty countings. Spacing between plants was  $1 \times 1$  foot.

The development of leaves is more in late strains than in early types and like tillers, the development of leaves reaches their maximum sooner in early varieties than in late types more especially in the transplanted series.

The character of leaf growth is easily affected by the fertility of the soil and environmental conditions. It is variable like tillers and is therefore of not much use in the present scheme of classification.

#### 4. Plant height.

The height is measured from the level of the ground to the joint of the panicle (ear-head) with the stem, which is visible by the presence of a ring of ciliate hairs. Those types that are sown broadcast are generally short in nature. Their average range lies between 60 to 80 cm. The shortest type is *sathi* (No. 132) which is about

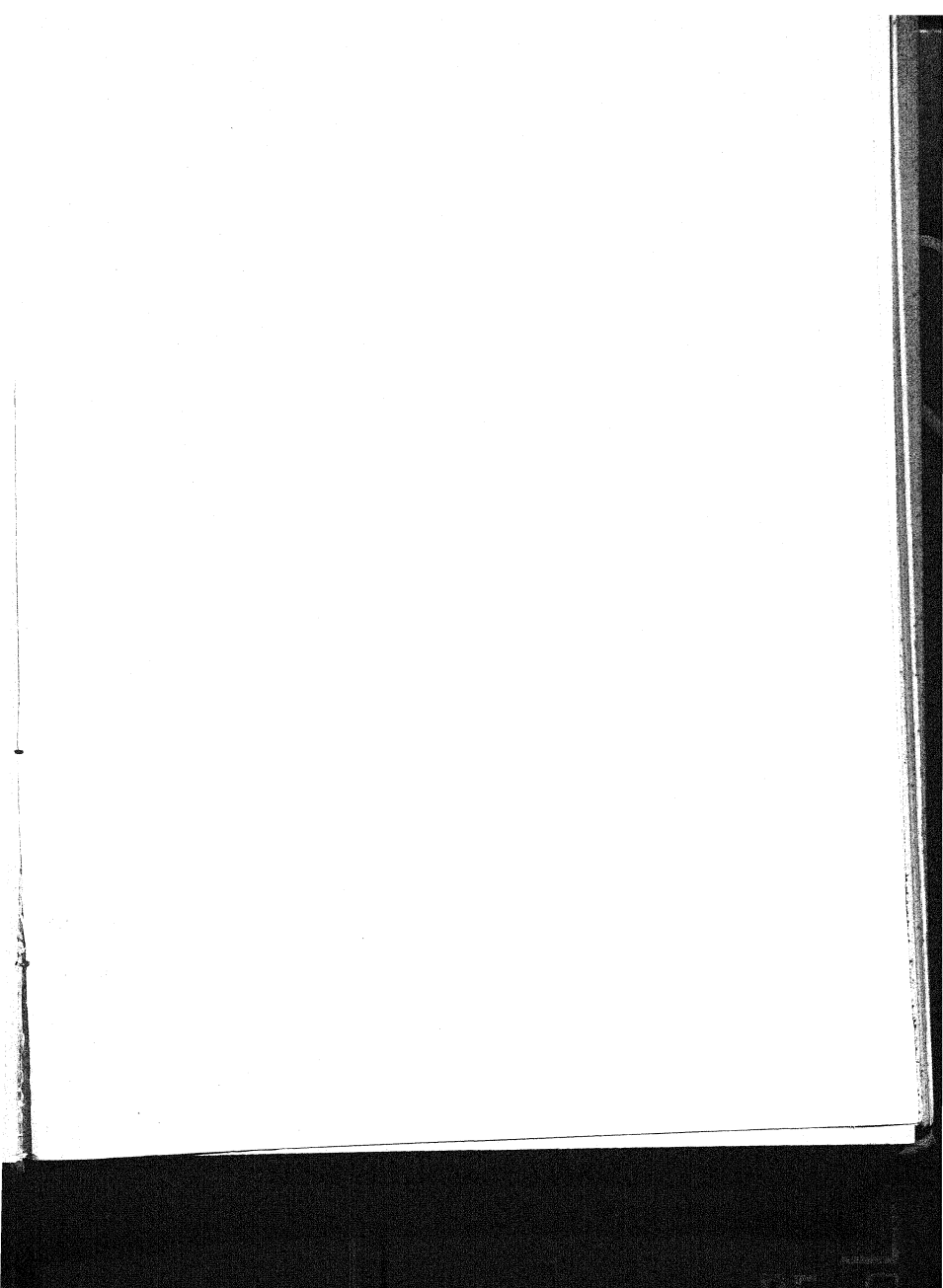
40 cm. in height. Transplanted kinds, on the other hand, are taller than the broadcast. Their average range lies between 80 to 110 cm., although some reach more than 110 cm. The maximum height is shown by Type No. 32 which is 152 cm. in length. Early varieties, both when sown broadcast or transplanted, show a markedly greater rapidity in attaining the limit of their height than the late varieties (Table VII).

TABLE VII.

*Showing the rate of growth in height of the different strains as indicated by the average height of plants measured at successive one week periods in cm.*

Periods 1928		SOWN BROADCAST (12TH JULY)		TRANSPLANTED (SOWN IN NURSERY ON 6TH JUNE AND TRANSPLANTED ON 12TH JULY)		
		Strains				
		Early No. 132	Late No. 128	Early No. 7	Medium No. 21	Late No. 25
August	1 . . .	9.4	8.2	18.3	18.7	20.3
”	8 . . .	10.4	10.9	20.4	21.2	22.9
”	15 . . .	14.4	13.5	24.2	22.8	25.0
”	22 . . .	20.3	19.8	33.3	28.8	30.9
”	29 . . .	35.3	22.8	59.9	38.8	34.9
September	5 . . .	40	31.6	88.2	65.1	41.3
”	12 . . .	42	48.7	98.4	92.5	46.6
”	19 . . .	..	73.5	99.4	110.9	51.3
”	26 . . .	..	74.2	..	112.1	63.4
October	3 . . .	..	..	..	112.8	84.5
”	10 . . .	..	..	..	..	118.6
”	17 . . .	..	..	..	..	138.8
”	24 . . .	..	..	..	..	145.9
”	31 . . .	..	..	..	..	146.8
November	7 . . .	..	..	..	..	147.2

The figures are shown only up to their maximum limits and each figure is the average of twenty countings. Spacing between plants was 1×1 foot.



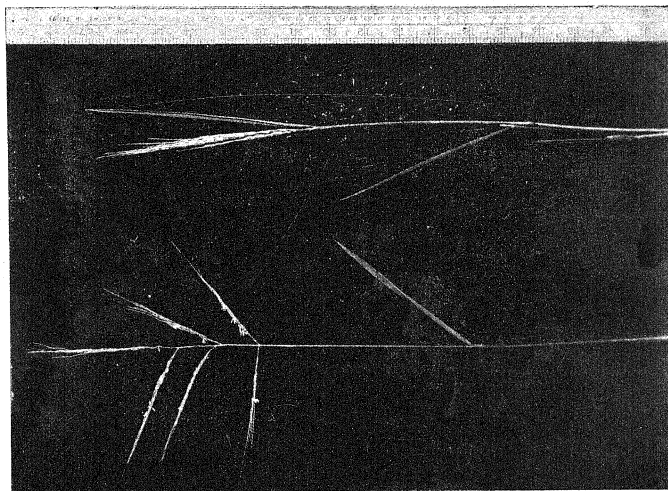


Fig. 2. Typical wild rice

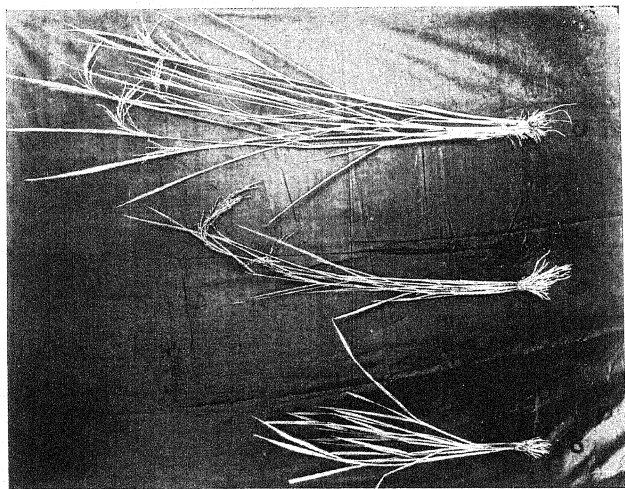


Fig. 1. a, *saxif* b, broadcast c, transplanted

The broadcast varieties, being short, are less liable to fall down than the transplanted kinds which are usually tall, but the advantage gained is more than counter-balanced by poor tillering and small panicle which is associated with short habit (Plate I, 1). Plants may be erect, spreading or trailing prostrate depending on the strength of the stem. The common types mostly remain erect in the young condition and become more or less spreading near ripening. We can divide the rice as short, medium and tall varieties, and the character may be of use for saving the plants from the direction of strong winds, but it is not very safe to use it as a distinguishing character, because the height is variable and depends on the fertility of the soil and the method of cultivation, whether sown broadcast or transplanted.

The difference in the vegetative growth, as measured in terms of number of tillers, leaves and height of a plant, allows some distinction to be made between various types, but all these vegetative characters as described, being dependent on environmental and seasonal conditions are variable and are therefore not useful as a basis for the scheme of classification.

#### 5. Ligule. (Plate II, 2.)

At the junction of the leaf-blade and the stem there are two small papery out-growths lying opposite the stem. These are called ligules. Their colour is either white or purple. In the latter case the leaf-sheath is always coloured deep purple. It is a morphological character of minor importance and does not show any variation.

#### 6. Auricle. (Plate II, 2.)

These are two ear-like hairy out-growths arising from the same place as the ligule, but are projected out sideways instead of lying flat on the stem, like the ligule. In the majority of cases, their colour is white, but only in a few types where the colour of the leaf-sheath is deep purple, they may be of purple colour. Their colour, when present, is more distinct and persistent than that of the ligules. Auricle is present in almost all types and, like ligule, is also a morphological character of minor importance.

#### 7. Colour relationship in the cultivated rice of the United Provinces. (Plate II.)

Different colours are found in different parts of the rice plant. The most common colours are yellow, purple, black, orange, red, and brown. Different shades of each as light and deep also exist. In the majority of cases these colours disappear in the mature plant. In the ripe grain the colours are fixed during maturity and serve as a useful distinguishing character. Sometimes these colours appear in non-coloured plants, only later on near maturity, but in such cases they are always faint. According to Mitra<sup>1</sup>, coloured factors are generally dominant over non-

<sup>1</sup> Mitra, S. K. Colour inheritance in rice. *Mem. Dept. Agri India, Bot. Ser.*, Vol. XV, January 1928, p. 101.

coloured ones. Parnell<sup>1</sup> also states that purple colour in the tip of the spikelet, at the base of the leaf-sheath and in the stigma is dominant, to the absence of purple in these parts. The important parts of the plant where colour is present are the leaf-sheath, the stigma, the apiculus, the outer glumes, the inner glumes and the kernel. Their colour-relationship is discussed below.

(a) *Leaf-sheath.* Two types of sheath-colours are met with in the United Provinces, one violet or purple and the other green. Out of a total of 135 varieties classified, 68 possess pale-green leaf-sheath, while 67 purple. The green may be pale green assuming an almost yellow tint or light green, which is lighter than the colour of the leaf. The extent of the purple colour varies considerably. It may range from a light pinkish tint to deep black purple. It generally appears early in the seedling stage, becomes intense after about a month's growth, when the real colour of the sheath is known. Near the ripening time it begins to fade away and may disappear altogether in certain cases. It is therefore only possible to distinguish various colours during early stages of growth. Generally speaking, deep intense colours remain constant throughout, with slight alteration; while lighter colours disappear near ripening. According to Kikwa<sup>2</sup>, the violet rices contain in the epidermis of the plant a certain violet colouring matter, which almost entirely covers the colour of the chlorophyll in the young stages and becomes thin later on, being washed away by rains. Sheath-colour is of a useful diagnostic character, but as it is not of any economic importance, it has not been employed in the present scheme of classification. In the United Provinces all the varieties, which possess a deep purple-coloured leaf-sheath, invariably possess the coloured apiculus (tip of the spikelet), but in a few kinds where leaf-sheath colour is light or dull purple, the apiculus is colourless. The reverse of this, that when the apiculus is of red or black purple colour, the leaf-sheath should also possess the same colour is not found in all cases. There are a few varieties, where the apiculus is coloured and the leaf-sheath is green (Table VIII).

Graham<sup>3</sup> states that there is a close relationship of colours between the leaf-sheath and the apiculus, and wherever the colour is not visible it is due to a very fleeting colour in the sheath.

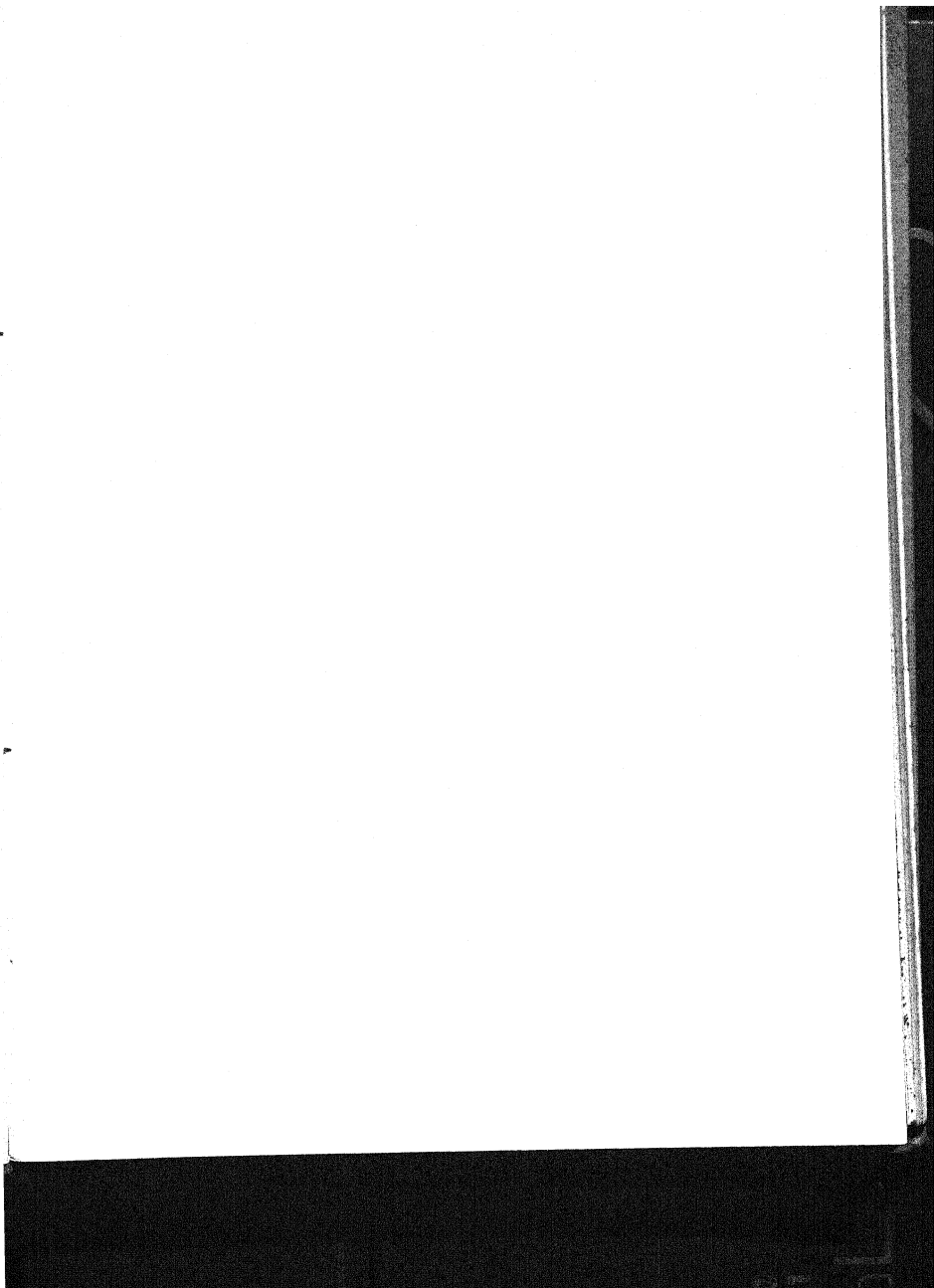
As regards the colour-relationship between the leaf-sheath and the kernel, all the varieties which have a green leaf-sheath do not necessarily possess white kernels, and *vice versa* (Table VIII). Thus the relationship does not seem to be very close. Thadani<sup>4</sup>, however, states that all the varieties with a green leaf-sheath have a white kernel. This may be true of Sindh, but the writer has come across a few types in the United Provinces in which the leaf-sheath is green and the kernel is red (type No. 116 and 126, Table VIII).

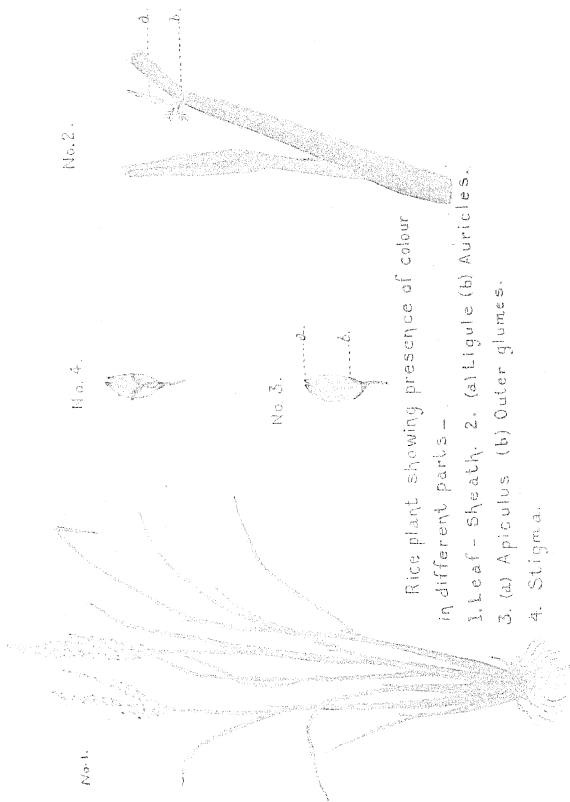
<sup>1</sup> Parnell, F. R., and others. The inheritance of characters in Rice. *Mém. Dept. Agri. India, Bot. Ser.*, Vol. IX, No. 2, 1917.

<sup>2</sup> Kikwa, S. *Ibid.*, p. 21.

<sup>3</sup> Graham, R. J. D. *Ibid.*, p. 220.

<sup>4</sup> Thadani, K. I. *Ibid.*, p. 122.





Rice plant showing presence of colour

in different parts -

1. Leaf - Sheath. 2. (a) Ligule (b) Auricles.

3. (a) Apiculus (b) Outer glumes.

4. Stigma.

(b) *Stigma* (Plate II, 4). The colour of the stigma is a constant feature and is of a useful diagnostic character. Common colours are white and black, the former predominating, being found in 108 types out of a total of 135 classified here. Graham<sup>1</sup> reports the presence of red stigma in the Central Provinces while Beale<sup>2</sup> states that it is absent in the Burmese rices. The writer has come across three varieties in the United Provinces in which the stigma is of light pink or light purple colour (Table VIII). As regards the colour-relationship of stigma with that of leaf-sheath, it has been found in the United Provinces that when the stigma is coloured the leaf-sheath is always coloured and when the stigma is white, the leaf-sheath may be purple or green (Table VIII). The purple of the sheath in the latter cases is always light or dull purple. This agrees with Beale's statement about Burmese rices. Hector<sup>3</sup> broadly classifies Bengal varieties according to the colour-relationship in the leaf-sheath, the apiculus and the stigma as follows :—

1. Leaf-sheath, apiculus and stigma coloured.
2. Leaf-sheath and apiculus coloured, but stigma colourless (white).
3. Leaf-sheath green, but apiculus and stigma coloured.
4. Only apiculus coloured, stigma and leaf-sheath colourless.

He is doubtful of the existence of the last two combinations in Bengal. In the United Provinces, the writer has not come across the combination No. 3 but the condition No. 4 does exist in a few types (No. 89, 6, 106 and 79 ; Table VIII).

(c) *Apiculus* (Plate II, 3). This is the tip of the spikelet formed by the union of the extreme points of both the inner glumes. In the majority of cases it is of common colour (pale yellowish white) and has uniform colour with the common colour of the inner glumes. In such cases the colour of the tip appears as dull white or light brown, according as the light yellow of the glumes fades away, or gets intensified near ripening. Purple colour when present may be red purple or deep purple (almost black). In the majority of cases, the colour is best seen a few days after emergence of the ear from the leaf-sheath. Generally it becomes faint near ripening time, or may disappear altogether when the colour is light. When it is intense, it persists as a black spot till the maturity of the grain. This character is of great help in roguing a pure field. It is closely associated with a more prominent character of leaf-sheath colour and hence is of not much use in the present scheme of classification. Beale<sup>4</sup>, however, has broadly grouped the Burmese types according to the combination of the colour character in the apiculus and the stigma. As regards its correlation with the stigma colour, although simultaneous colouring is common, the colour of the apiculus is independent of the colour of the stigma (Table VII).

<sup>1</sup> Graham. *Ibid.*, p. 226.

<sup>2</sup> Beale, R. A. *Ibid.*, p. 7.

<sup>3</sup> Hector, G. P. Observation on the inheritance of Anthocyan pigment in paddy varieties. *Mem. Dept. Agri. India, Bot. Series*, Vol. VIII, No. 2, Nov. 1916.

<sup>4</sup> Beale, R. A. *Ibid.*, p. 8.

TABLE VIII.

*Showing colour relationship in the cultivated rices in the United Provinces.*

Strain No.	Leaf-sheath	Stigma	Aplenus	Kernel	Outer glumes	Inner glumes	REMARKS
134	Black purple .	Black .	Black .	Red .	Deep purple .	Common colour with brown markings.	Common colour.—Ordinary pale yellowish white colour of the paddy grains (un-husked rice).
80	Red purple .	Do. .	Black purple .	White .	Do. .	Dull common, with brown markings.	
124	Purple .	Do. .	Black .	Red .	Do. .	Common, with brown markings.	
2	Light purple .	White .	Red purple .	White .	Light purple .	Do. .	
112	Do. .	Light pink.	Common .	Red .	White .	Do. .	
80	Black purple .	Black .	Black purple .	White .	Do. .	Dull common.	No colour.—No special colour separate from the inner glumes.
117	Light dull purple.	Light purple	No colour .	Dirty red-dish.	Do. .	Deep orange red.	
7	Light purple .	White .	Common .	White .	Do. .	Common .	
65	Dull purple .	Do. .	Do. .	Do. .	Do. .	Do. .	
73	Light purple .	Do. .	Do. .	Do. .	Do. .	Do. .	
113	Do. .	Light purple	No colour .	Light red .	Do. .	Dull orange brown.	Pale green differs from light green in having some yellowish tint.
80	Pale green .	White .	Black .	White .	Light purple .	Common .	
6	Do. .	Do. .	Black purple .	Do. .	White .	Dull brownish red.	
126	Do. .	Do. .	Common .	Red .	Do. .	Common with brown markings.	
116	Do. .	Do. .	Do. .	Do. .	Do. .	Dull common.	
14	Black .	Black .	Black .	White .	Purple .	Common with purple markings.	
46	Black purple .	Do. .	Red purple .	Do. .	White .	Common.	
106	Light green .	White .	Black .	Do. .	Red purple .	Black.	
79	Pale green .	Do. .	Black purple .	Do. .	Orange brown	Common.	

### 8. Water requirement.

Rices generally fall into three main classes in regard to their water requirement, viz., upland, common and aquatic rices. It seems probable that some of

the common varieties, in consequence of repeated cultivation in dry or flooded fields, for many years, have acquired the character of either enduring drought or standing in floods and growing fairly well on lands, where the present day common rice usually fail. Some kinds of upland rice may be direct descendants of true upland species such as *O. granulata* Nees and *O. Latifolia* Desv, which according to Watt quoted by Kikwa<sup>1</sup> are still found in mountainous districts of India. Watt<sup>2</sup> places all upland cultivated rice under his variety *abuensis*, and does not regard these in anyway derived from *O. granulata*, but considers *O. Latifolia* to have contributed some help in producing upland rice by hybridization.

In the United Provinces those varieties that are grown in dry conditions are sown broadcast and are early ripening, while those cultivated in tanks and marshy lands are generally transplanted and are late in ripening. The largest number consists of common varieties which are generally transplanted and are intermediate in ripening. It is useful to classify rice according to their water-requirement, but as some common varieties may be grown under all conditions, it is very difficult to draw a line among these three classes.

#### 9. Cold weather rice.

It is generally known as *boro* or *jethi dhan*. It is sown in December—January, transplanted in February and harvested in May—June. It is an interesting crop as, unlike the main rice crop of the Province cultivated during the *Kharif* season (June—November), it is cultivated during winter months. The rice is coarse, ill-flavoured and is generally cultivated on the margins of lakes and ponds in those districts, where these water reservoirs are common. The spikelets are deciduous and an uneven maturity is a common feature in them. They do not possess any distinctive morphological feature and can be sown broadcast or transplanted during the *Kharif* season as well. The *boro* rice as a class thus does not constitute a separate group possessing distinctive features but are common rice cultivated in winter on marshy lands. This is probably because of the scarcity of water in that season on ordinary fields.

#### 10. Wild rice. (Plate I, 2.)

The common varieties of wild rice found in the United Provinces belong to the species *Oryza sativa* L. and are commonly found growing round the edges of lakes and marshes. The popular name is *tinni* or *passahi*. They often appear as weed in cultivated rice and are a frequent source of contamination. These wild types are characterised by the presence of long rough awns and deciduous nature of their spikelet.

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<sup>1</sup> Kikwa, S. *Ibid*, p. 14.

<sup>2</sup> Watt, Sir G. *Ibid*, Vol. V, pp. 504-506.

## IV. REPRODUCTIVE CHARACTERS.

1. *Inflorescence.*

It consists of two parts, a lower known as peduncle and an upper part called panicle or the ear-head. The panicle has a main rachis bearing primary and secondary branches. The rachis may be either erect, curved or drooping. In the last case, it bends in a sharp curve. The inflorescence is generally erect in short sized early-ripening, broadcast, varieties, and drooping in tall, late, and transplanted kinds.

(a) *Peduncle.* This is the uppermost internode of the plant supporting the panicle. The major part of it remains covered by the leaf-sheath, but for convenience that part of it which emerges above the leaf-sheath is called the peduncle proper. At the junction of the peduncle and panicle there is a ridge of ciliate hairs. This ridge is also the starting place of the lowest branch of flowers. The peduncle is said to be "enclosed" when the ridge is enclosed within the leaf-sheath and "exserted" when the ridge is free and visible above the leaf-sheath (Plate III, 1). The extent to which the peduncle is exserted varies. Generally in late fine-grained kinds the ciliate ridge is far above the leaf-sheath, and the peduncle is called "far exserted," and in broadcast early-ripening, coarse types it just emerges out of the leaf-sheath and the peduncle is called "just exserted". Between these two extremes all gradations of exsertion exist. In the case of *sathi* (No. 132) a most prominent broadcast variety of the Province, the whole inflorescence remains almost enclosed within the leaf-sheath cover, and only emerges a little at the top and on the sides near the ripening of the ear-head (Plate III, 1, a). This character is found only in this variety, and is very useful as a protection against the ravages of the rice sapper called *gundhi* (*Leptocorisa varicornis* F.) which sucks away the milky juice of the young spikelets. The length of the peduncle is of a diagnostic character, and Watt<sup>1</sup> makes use of it in classifying the cultivated rices, and groups them into three main classes as follows:—

- (i) Tall habit of growth, ear protruded from the sheath, feathery and drooping and fine grain.
- (ii) Short habit of growth, ear not so prominent and carried more erect than (i) and thick grain.
- (iii) Strong short stem, ear partially enclosed in the sheath.

It has been seen with our cultures that when grown in rich fields, the emergence of the peduncle above the sheath is less as compared to when grown in poor dry fields; also in years of poor growth, there is greater emergence than in years of good growth. The character is thus liable to fluctuate under different conditions and is not employed as a basis in the present scheme of classification.

(b) *Panicle.* The length of the ear-head or the panicle is measured from the ciliate ridge up to the end of the top most spikelet. The shortest ear, being 18 to

<sup>1</sup> Watt, Sir. G. *Ibid*, Vol. V, p. 503.

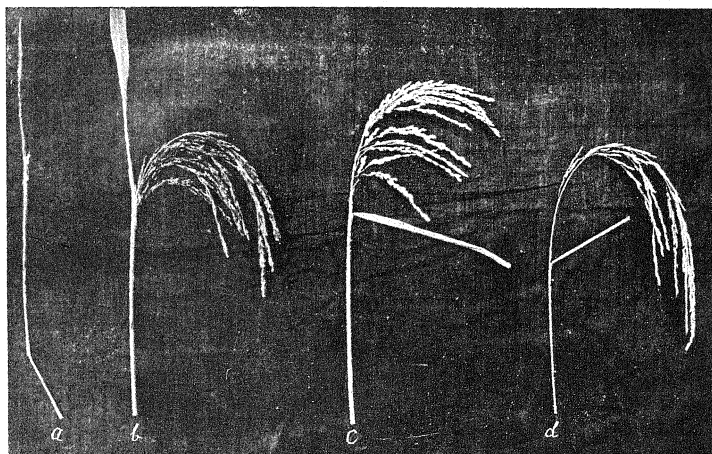


Fig. 1. a. covered b. enclosed c. just exerted d. far exerted

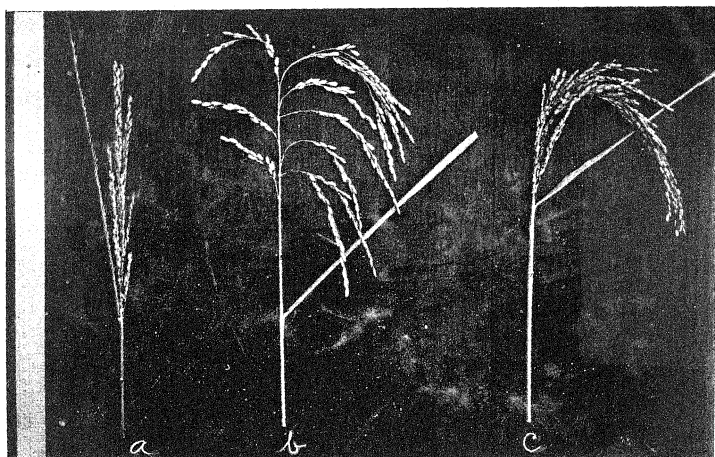
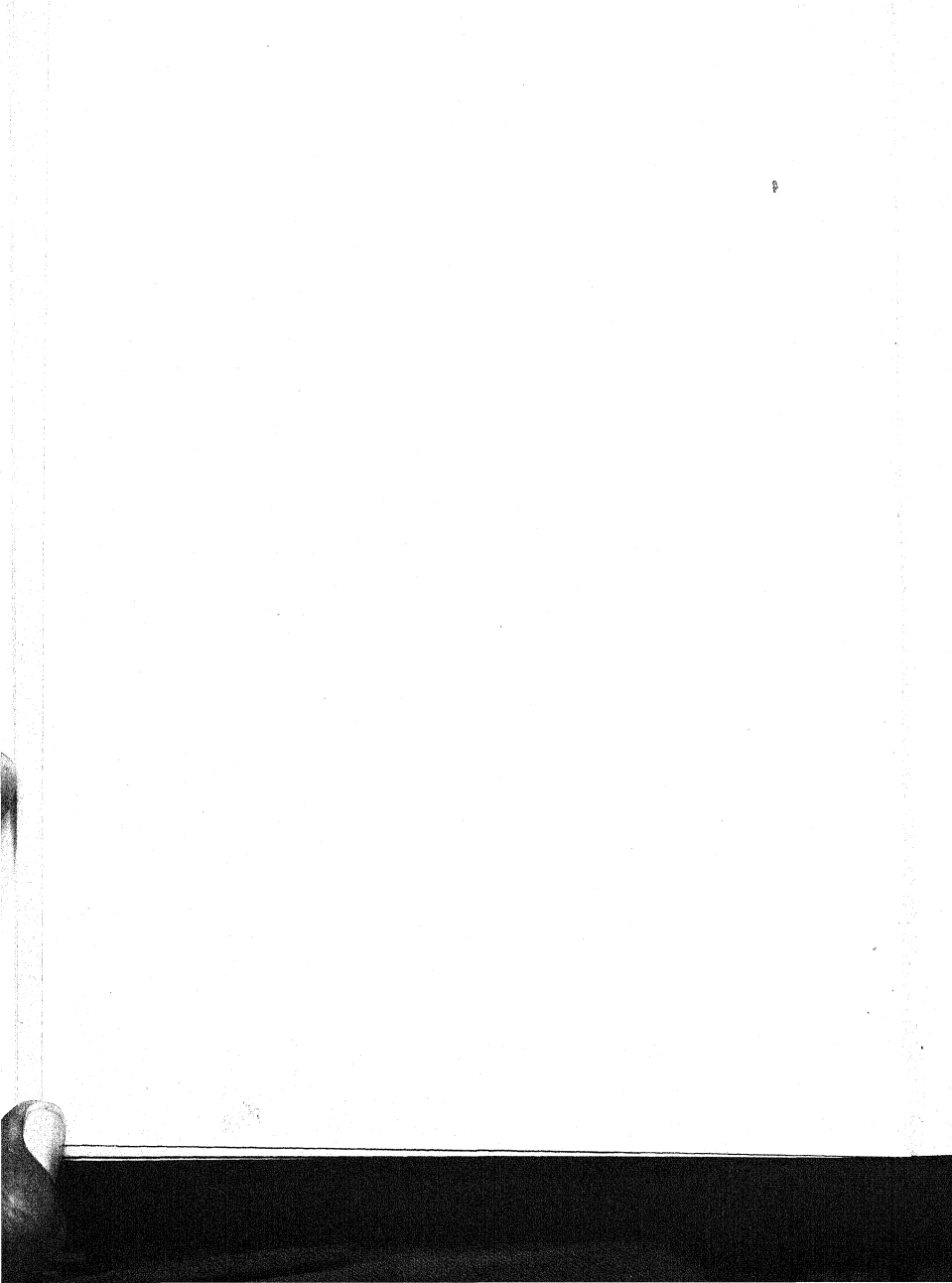


Fig. 2. a. erect b. spreading c. curved approximate



20 centimetres, is found in *sathi* (No. 132) an early ripening broadcast type, while the longest of 32.6 cm. in No. 19. The average range lies between 23 and 28 cm. The relationship between the length of the main panicle, tillering and the height of the plant was studied by working out a few correlations. The results are summarized below in Tables IX and X.

TABLE IX.

*Showing correlation between tillering and length of the main panicle.*

Strain No.	Mean No. of tillers	Mean length of panicle in cm.	Co-efficient of correlation between tillering and length of panicle	REMARKS
23 . . .	8.5	29.5	$0.37 \pm 0.05$	Correlation appreciable.
22 . . .	8	27.2	$0.16 \pm 0.06$	Correlation slight.
1 . . .	11.2	29.5	$0.29 \pm 0.06$	Correlation rather appreciable.
25 . . .	13.3	29.8	$-0.17 \pm 0.06$	Correlation slight.
15 . . .	22.0	31.1	$0.30 \pm 0.06$	Correlation appreciable.

Fifty observations were made in each case.

The amount of correlation within each pure strain does not seem to be very close although it is appreciable in some cases. In type No. 25 it is negative, while in others it is positive.

TABLE X.

*Showing correlation between the length of the main panicle and the height of the plant.*

Strain No.	Mean length of the main panicle in cm.	Mean height of the plant in cm.	Co-efficient of correlation	REMARKS
109 . . .	18.3	56.06	$0.42 \pm 0.05$	Correlation close. fairly
23 . . .	29.5	147.3	$-0.33 \pm 0.06$	Correlation appreciable.
128 . . .	23.8	73.2	$0.48 \pm 0.05$	Correlation close. fairly
22 . . .	27.2	116.8	$-0.03 \pm 0.06$	Correlation negligible.

Fifty observations were made in each case.

From the above Table, it will be seen that, within each pure strain, the relationship between the length of the main panicle and the height of the plant is negative in some and positive in others. The amount of correlation also varies much. In some strains it is distinct, while in others it hardly exists.

The branches of the panicle are either primary or secondary and may be erect, spreading, curved approximate, or a combination of these conditions (Plate III, 2). Generally the lower branches are either erect or spreading, while the upper are approximate and curved. The average number of the branches of the panicle varies from 12 to 18. The smallest number of 9 is found in early ripening type No. 132, while the maximum of 28 in a late ripening type No. 66. It does not necessarily follow that all the late varieties possess greater number of branches than the early ones. Generally speaking, in the transplanted series, the types with long panicles have proportionately fewer branches, whereas those possessing short-panicles have a comparatively larger number. The latter types consequently appear denser or more compact. Gammie<sup>1</sup> makes use of the average number of primary branches in distinguishing the rices of the Bombay Presidency. It is not, however, possible to use this character as a basis for classification in the United Provinces as it has been found to be very variable. A detailed examination of these panicle characters was undertaken with many varieties. The results of a few representative types is shown in the following Table :—

TABLE XI.  
*Ear-head characters of typical rice varieties of the United Provinces.*

Strain No.	No. of days required from sowing (in broadcast) or transplanting to maturity	Mean length of ear-head in cm.	Mean No. of branches in the panicle	Mean No. of spikelets per ear
<i>Broadcast early—</i>				
132 .	71	20.3	9	90
133 .	75	17.8	9	82
<i>Late—</i>				
123 .	98	25.5	13	195
128 .	94	23.8	13	207
<i>Transplanted early—</i>				
2 .	80	29.9	14	210
49 .	86	25.5	15.5	312.5
3 .	86	32.0	13	180
118 .	88	26.0	16.5	262.5
19 .	88	32.5	13.5	202.5
43 .	88	25.5	22	470
<i>Medium—</i>				
112 .	102	29.9	15	250
90 .	108	26.7	17.5	276
<i>Late—</i>				
59 .	125	21.7	19	350
56 .	129	25.5	15	234
82 .	131	29.9	16	440
110 .	127	28.0	20	475
66 .	127	21.7	28	625

Each figure is the average of twenty observations.

<sup>1</sup> Gammie, G. A. *Ibid*, p. 89.

The relationship between number of branches and tillering was also studied. The results are summarized in Table XII.

TABLE XII.

*Showing correlation between tillering and the number of branches in the panicle.*

Strain No.	Mean No. of tillers	Mean No. of branches	Co-efficient of correlation	REMARKS
25 . .	13.3	14.5	$0.09 \pm 0.06$	Correlation negligible.
23 . .	8.5	13.8	$0.09 \pm 0.06$	Do.
22 . .	8	15.4	$0.32 \pm 0.05$	Correlation appreciable.
1 . .	11.2	14.7	$-0.13 \pm 0.06$	Correlation slight.
70 . .	22.0	18.9	$0.41 \pm 0.05$	Correlation fairly close.

50 observations were made in each case.

The correlation is fairly close in Nos. 22 and 70, both of which possess greater number of branches than others.

## 2. Time of ripening of the flower (Duration).

In transplanted kinds the earliest types flower by the end of August or by about the beginning of September, if sown in the nursery in the first week of June, *i.e.*, in about 80 or 90 days after sowing, while the latest types flower about the middle of October or even a few days later taking as many as 135 days. This range of 40 to 50 days can be divided into the following four periods of flowering.

Duration	Maximum No. of varieties flowered during that period	Range of days required from transplanting to maturity
1. Early.—Flower from 30th of August to 12th September.	48	76-92.
2. Medium.—Flower from 13th of September to 30th September.	8	95-108.
3. Late.—Flower from 1st of October to 15th October .	55	112-131.
4. Very late.—Flower from 16th of October to 22nd October.	11	131-133 or more.

In determining the earliness of varieties of rice, early flowering is usually considered as an index of early maturity. This, however, is not always the case. (Table XIII.)

TABLE XIII.

*Flowering and ripening period of the rices in the United Provinces.*

Strain No.	Days from transplanting to flowering	Days from transplanting to ripening
<i>Early—</i>		
122 . . . . .	51	82
124 . . . . .	51	76
63 . . . . .	54	76
29 . . . . .	54	80
<i>Medium—</i>		
108 . . . . .	64	100
78 . . . . .	64	95
4 . . . . .	66	95
<i>Late—</i>		
26 . . . . .	89	131
22 . . . . .	90	122
76 . . . . .	90	121
93 . . . . .	91	129
52 . . . . .	91	125

Thus the types No. 122 and 124 flower about the same time, but there is difference in the time of their maturity. A similar behaviour is shown by the late varieties (in the table) among themselves.

The interval between flowering and maturity may vary also from season to season in the same variety, although it is a fairly constant one, being about 3 to 4 weeks for the early and intermediate strains and about 5 to 6 weeks for the late ones in these Provinces.

TABLE XIV.

*Seasonal variation in the ripening period.*

Strain No.	Number of days from flowering to maturity		
	1926	1927	1928
<i>Early—</i>			
122 . . . . .	26	33	31
29 . . . . .	24	33	26
3 . . . . .	24	31	32
19 . . . . .	27	33	34
<i>Medium—</i>			
108 . . . . .	34	31	36
4 . . . . .	33	30	29
85 . . . . .	30	26	24
<i>Late—</i>			
95 . . . . .	41	35	41
93 . . . . .	41	35	36
83 . . . . .	42	33	33
62 . . . . .	43	35	34
69 . . . . .	41	37	34

Early varieties generally take less time to ripen than the late ones. This is most probably due to change in the temperatures of the season. The temperature by the end of September or beginning of October, when the early types mature, is about 98° F., while about the beginning or middle of November, the time for the maturity of late kinds, it ranges between 80° to 84° F.

The periods for which the plants in a single culture continue to flower is generally longer for the early strains, and much shorter for the late ones. This is probably because when the early types flower in September, there is much moisture in the soil, and the air is more humid than in October when the late strains flower.

The broadcast varieties, on the other hand, as represented by *sathi* (No. 132) flower by the end of August, *i.e.*, after about 45 days when sown about the middle of July, while *deola* (No. 128) and other late kinds of the broadcast series flower about the middle of September, when sown on the same date as *sathi*. The broadcast kinds usually mature within a month's time after flowering. Their usual range from sowing to maturity lies between 70 to 107 days. Early kinds are sown on the higher fields and the late ones in the low-lying places where the continuous supply of water is assured, while the medium kinds on land of intermediate character.

It has been observed that some varieties flower after a certain period, irrespective of their date of sowing or transplanting, while others flower at a fixed time of the year, no matter whether sown early or late. The former mode of flowering has been termed "periodically fixed" and the latter "timely fixed" by Mitra.<sup>1</sup> The following Tables (XV and XVI) will elucidate this point as shown by the rices in the United Provinces.

TABLE XV.

*Showing the time of flowering of the "periodically fixed" type of rices.*

Strain No.	Year	Date of transplanting or sowing broadcast	Number of days from sowing (in broadcast) or transplanting to flowering
132 . . . . .	1926 .	25th July . .	49
	1927 .	7th " . .	44
	1928 .	12th " . .	45
139 . . . . .	1926 .	25th " . .	49
	1927 .	7th " . .	46
	1928 .	12th " . .	47
128 . . . . .	1926 .	25th " . .	62
	1927 .	7th " . .	67
	1928 .	12th " . .	65
7 . . . . .	1926 .	18th " . .	53
	1927 .	7th " . .	56
	1928 .	12th " . .	53
39 . . . . .	1926 .	18th " . .	51
	1927 .	7th " . .	48
	1928 .	12th " . .	51
21 . . . . .	1926 .	18th " . .	64
	1927 .	7th " . .	64
	1928 .	12th " . .	62

<sup>1</sup> Mitra, S. K., and others. Seasonal variation in paddy. *Agri. Jour. India*, Vol. XIX, 1924.

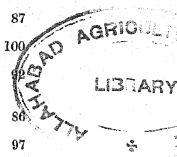
It is the broadcast varieties and the early types of the transplanted series that are mostly "periodically fixed" in the United Provinces and a great majority of these types show this character, while the "timely fixed character" is shown only by some varieties of the late types (Table XVI).

TABLE XVI.

*Showing the time of flowering of the "timely fixed" type of rices.*

Strain No.	Year	Date of transplanting	Date of flowering	No. of days from transplanting to flowering
90	1926	18th July	26th September	70
	1927	7th "	23rd "	78
	1928	12th "	25th "	75
4	1926	18th "	16th "	60
	1927	7th "	14th "	69
	1928	12th "	16th "	66
23	1926	18th "	13th October	87
	1927	7th "	15th "	100
	1928	12th "	12th "	82
26	1926	18th "	12th "	86
	1927	7th "	12th "	97
	1928	12th "	9th "	89
34	1926	18th "	17th "	91
	1927	7th "	15th "	100
	1928	12th "	12th "	92

Varieties are either sown broadcast or transplanted according to the facilities available in different parts of the Provinces, and sometimes the same variety



may be sown under both conditions in the same district. This causes a great difference in the dates of ripening of the same variety, and presents a real difficulty in making use of duration as a basis for classification. Again the same variety becomes late in ripening as we go from the western to the eastern side of the Province. *Anjana* (No. 44) grows all over the Province, it is earliest ripening in Dehradun (extreme west); is late by about 4 or 5 days in Bareilly (central region), and about 11 days in Gorakhpur (extreme east) as compared to Dehradun. Again *Ajan Dhan* (No. 65) is late in ripening by about a week in Azamgarh (east) as compared to its growth in Dehradun. The character of the duration of the crop is still the most important feature from an agricultural point of view, and is taken advantage of by the farmers in discriminating their various kinds, but as it is affected by the time of sowing, irrigation water, soil and climatic conditions, it is not such a constant character as to be employed in the present scheme of classification.

### 3. Pollination.

Self-pollination is the general rule in the rice plant although occasional cases of natural cross-pollination are also met with. The percentage of natural cross-pollination, however, is not much. It does not seem to exceed 2 per cent. at the Botanical farm, Cawnpore, and is limited to adjacent plants growing within a radius of a few feet. Parnell<sup>1</sup> reports about 2 to 4 per cent. in Madras and Hector<sup>2</sup> about 4 per cent. in Bengal. The process of the opening of the flower and pollination varies. The anthers may dehisce before the opening of the glumes (as in type No. 7), at the time of the opening of the glumes (type No. 1), or after they have emerged (No. 3). The first two cases are more frequent. The stigma, as a general rule, is receptive by the time the glumes open, and in the majority of cases they get covered by pollen grains before opening or just when opening. In *sathi* (No. 132), a famous broadcast early ripening variety of the United Provinces, the flowers are cleistogamous, and the glumes of the flowers, probably because of the sheath cover of the ear-head, remain closed throughout their life time and never open (Plate III, I). Farneti<sup>3</sup> also reports the presence of cleistogamous flowers in rice-heads in Italy. A close study has been made of the opening of the flowers on single ear-heads in a few representative types of rices in the United Provinces. The general conclusions are summarized in Tables XVII and XVIII.

<sup>1</sup> Parnell, F. R., and others. The inheritance of characters in rice. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. V, No. 7.

<sup>2</sup> Hector, G. P. Notes on pollination and cross fertilization in the common rice plant, *Oryza Sativa*. *Mem. Dept. Agri. India, Bot. Series*, Vol. VI, No. 1.

<sup>3</sup> Farneti, R. Spora di brusone del riso-Atti Ist. Botan. dell' Univ. di pavia., XVIII, 1921, p. 109.

TABLE XVII.

*Showing the time of the day when opening of the flowers takes place.*

Time of the day	NUMBER OF FLOWERS OPENED ON ONE EAR-HEAD							Total
	8	9	10	11	12	1	2	
Temperature	88°F.	89°F.	91°F.	92°F.	93°F.	94°F.	96°F.	
<i>Strain No.</i>								
<i>Early varieties. (September 10th.)</i>								
7 . . .	0	3	4	24	10	4	0	45
134 . . .	0	0	0	21	16	5	0	42
29 . . .	0	0	0	5	20	0	0	25
47 . . .	0	0	2	28	21	0	0	51
18 . . .	0	0	3	42	0	0	0	45
14 . . .	0	0	1	41	13	2	0	67
2 . . .	0	0	0	34	6	0	0	40
8 . . .	0	0	1	45	8	0	0	54
55 . . .	0	0	0	5	13	8	0	26
31 . . .	0	0	1	29	8	0	0	38
Total .	0	3	12	274	115	19	0	423
Percentage .	0	7	2.8	64.8	27.2	4.5	0	100
<i>Late varieties. (November 1st.)</i>								
Temperature . .	76°F.	77°F.	79°F.	81°F.	82°F.	83°F.	83°F.	
129 . . .	0	0	0	6	29	0	0	35
54 . . .	0	0	0	9	4	0	0	13
125 . . .	0	0	0	0	5	5	1	11
99 . . .	0	0	0	4	29	3	0	36
70 . . .	0	0	0	0	8	15	5	28
61 . . .	0	0	2	11	5	0	0	18
110 . . .	0	0	0	0	11	28	3	42
Total .	0	0	2	30	91	51	9	183
Percentage .	0	0	1.1	16.4	49.7	27.8	5	100

At Cawnpore, the opening of the glumes generally takes place between 9 A.M. and 1 P.M. in the early varieties, and between 11 A.M. and 1 P.M. in the late varieties. Most vigorous flowering is seen between 10-30 to 11-30 A.M. in the early types, and between 11-30 to 12-30 in the late types. In no case the flowers continue opening after 2 P.M. in the early varieties and an hour later in the late varieties. The temperature at which the flowers open in the early varieties ranges from 90° to 94° F. and in the lates from 80° to 84° F. The optimum being 92° F. for the former and 82° F. for the latter. As a general rule, in the individual panicle, the flowering proceeds from above downwards, but a few flowers do not open near the top in the beginning. Weather conditions, at the time of flowering, affect a good deal the time of opening, sunshine hastening the process and clouds and rains retarding it. The entire period required by a single flower, from the opening to the closing of the glumes, is about 50 to 60 minutes. Late in the season, some varieties may take about an hour and a quarter.

The number of days a single ear-head requires to flower completely was also studied. This is shown in Table XVIII.

TABLE XVIII.

*Showing the period of flowering of a single ear-head.*

Strain No.	NUMBER OF FLOWERS OPENED ON EACH DAY									Unopened and abortive	Total
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th		
<i>Early varieties.</i> (Sep 8th.)											
7 .	45	67	52	34	6	0	0	0	0	14	218
134 .	42	51	44	34	0	0	0	0	0	4	175
29 .	25	47	38	21	12	0	0	0	0	6	149
47 .	51	44	57	50	23	7	0	0	0	26	258
18 .	45	69	71	43	13	3	0	0	0	14	258
14 .	57	51	59	46	17	9	0	0	0	23	262
2 .	40	89	46	29	13	0	0	0	0	11	228
55 .	26	38	26	10	4	1	0	0	0	3	108
31 .	38	77	55	33	13	1	0	0	0	12	229
Total .	369	533	448	300	101	21	0	0	0	113	1,885
Percentage	19.5	28.3	23.8	16	5.4	1.1	0	0	0	5.9	100

TABLE XVIII.

*Showing the period of flowering of a single ear-head.*

Strain No.	NUMBER OF FLOWERS OPENED ON EACH DAY									Unopened and abortive	Total
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th		
<i>Late varieties (October 29th).</i>											
129 .	20	19	22	35	13	5	11	0	0	3	128
54 .	16	22	37	13	5	3	0	0	0	0	96
125 .	4	14	5	11	4	1	0	0	0	0	39
99 .	15	24	30	36	23	10	1	0	0	0	139
110 .	3	22	29	42	44	29	20	16	7	3	215
Total .	58	101	123	137	89	48	32	16	7	6	617
Percentage	9.4	16.3	19.9	22.2	14.4	7.76	5.2	2.6	1.13	1.11	100

The maximum flowering activity is reached in the second and the third day in the early varieties and on the third and the fourth day in the late varieties. The early varieties also finish opening their flowers sooner (*i.e.*, on the 6th day) than the late strains, which continue up to the 7th, and sometimes up to the 9th day. The difference in times of pollination and opening of flowers is associated with the lifeperiod of the plant and as an independent character for employment as a basis for classification, has nothing very much to recommend it.

#### 4. *Yielding capacity.*

Yield is a complex of various factors such as tillering power, number of grains per ear-head and sterility percentage in the panicle. In very early strains sown broadcast, this is generally low, presumably owing to the short period of growth. These strains have all a low tillering capacity and small sized panicles. The grains in these strains are generally coarse. In the transplanted series, on the other hand, the yield per plant in the late strains, is generally more than in the early strains; but it is not invariably the case. Some of the early types may yield well and also late strains may be poor yielders. The following table (XIX) will show the comparative yield in different strains.

At Cawnpore, the opening of the glumes generally takes place between 9 A.M. and 1 P.M. in the early varieties, and between 11 A.M. and 1 P.M. in the late varieties. Most vigorous flowering is seen between 10-30 to 11-30 A.M. in the early types, and between 11-30 to 12-30 in the late types. In no case the flowers continue opening after 2 P.M. in the early varieties and an hour later in the late varieties. The temperature at which the flowers open in the early varieties ranges from 90° to 94° F. and in the lates from 80° to 84° F. The optimum being 92° F. for the former and 82° F. for the latter. As a general rule, in the individual panicle, the flowering proceeds from above downwards, but a few flowers do not open near the top in the beginning. Weather conditions, at the time of flowering, affect a good deal the time of opening, sunshine hastening the process and clouds and rains retarding it. The entire period required by a single flower, from the opening to the closing of the glumes, is about 50 to 60 minutes. Late in the season, some varieties may take about an hour and a quarter.

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<i>Early varieties. (September 8th.)</i>											
7 .	45	67	52	34	6	0	0	0	0	14	218
134 .	42	51	44	34	0	0	0	0	0	4	175
29 .	25	47	38	21	12	0	0	0	0	6	149
47 .	51	44	57	50	23	7	0	0	0	26	258
18 .	45	69	71	43	13	3	0	0	0	14	258
14 .	57	51	59	46	17	9	0	0	0	23	262
2 .	40	89	46	29	13	0	0	0	0	11	228
55 .	26	38	26	10	4	1	0	0	0	3	108
31 .	38	77	55	33	13	1	0	0	0	12	220
Total .	369	533	448	300	101	21	0	0	0	113	1,885
Percentage	19.5	28.3	23.8	16	5.4	1.1	0	0	0	5.9	100

TABLE XVIII.

*Showing the period of flowering of a single ear-head.*

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	1st	2nd	3rd	4th	5th	6th	7th	8th	9th		
<i>Late varieties (October 29th).</i>											
129 .	20	19	22	35	13	5	11	0	0	3	128
54 .	16	22	37	13	5	3	0	0	0	0	96
125 .	4	14	5	11	4	1	0	0	0	0	39
99 .	15	24	30	36	23	10	1	0	0	0	139
110 .	3	22	29	42	44	29	20	16	7	3	215
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Percentage	9.4	16.3	19.9	22.2	14.4	7.76	5.2	2.6	1.13	1.11	100

The maximum flowering activity is reached in the second and the third day in the early varieties and on the third and the fourth day in the late varieties. The early varieties also finish opening their flowers sooner (*i.e.*, on the 6th day) than the late strains, which continue up to the 7th, and sometimes up to the 9th day. The difference in times of pollination and opening of flowers is associated with the lifeperiod of the plant and as an independent character for employment as a basis for classification, has nothing very much to recommend it.

#### 4. Yielding capacity.

Yield is a complex of various factors such as tillering power, number of grains per ear-head and sterility percentage in the panicle. In very early strains sown broadcast, this is generally low, presumably owing to the short period of growth. These strains have all a low tillering capacity and small sized panicles. The grains in these strains are generally coarse. In the transplanted series, on the other hand, the yield per plant in the late strains, is generally more than in the early strains; but it is not invariably the case. Some of the early types may yield well and also late strains may be poor yielders. The following table (XIX) will show the comparative yield in different strains.

TABLE XIX.

*Showing comparative yield per plant in early and late strains (1928).*

Strain No.	No. of days from sowing (in broadcast) or transplanting to maturity	Mean No. of tillers per plant	Mean yield per plant in gm.
<i>Broadcast varieties--</i>			
132 . . .	71	10	9.3
133 . . .	75	9	13.6
<i>Transplanted varieties--</i>			
<i>Early</i> 13 . . .	84	18.9	37.23
51 . . .	86	11.7	22.40
14 . . .	80	16.9	32.96
24 . . .	86	11.3	29.02
49 . . .	86	16.15	42.90
124 . . .	76	18.9	44.79
<i>Medium</i> 85 . . .	102	26.4	41.87
90 . . .	108	14.0	38.16
<i>Late</i> 62 . . .	127	26.4	69.4
34 . . .	131	21.6	66.50
98 . . .	133	31.6	50.25
94 . . .	129	11.1	30.10
82 . . .	131	23.1	40.80

Distance between plants was 1 x 1 foot.

The yield of straw is also of considerable importance as it is used as fodder in some places. The following are the comparative figures of grain and straw yields in a few strains (Table XX).

TABLE XX.

*Showing proportion of paddy grain to straw in various strains.*

Strain No.	Mean weight of grain of twenty plants in gm.	Mean weight of straw of twenty plants in gm.	PERCENTAGE		RATIO OF GRAIN TO STRAW		
			Grain	Straw	Grain	Straw	
<i>Early varieties—</i>							
39 . . . .	49.16	48.00	50.6	49.4	1.0	0.97	
1 . . . .	63.35	60.01	51.35	48.65	1.0	0.95	
3 . . . .	45.10	56.21	44.51	55.49	1.0	1.24	
<i>Late varieties—</i>							
15 . . . .	67.96	122.60	35.6	64.4	1.0	1.80	
67 . . . .	89.21	148.38	37.5	62.5	1.0	1.66	
23 . . . .	38.6	61.4	38.6	61.4	1.0	1.6	

Generally speaking, the percentage of the straw as compared with the grain is less in early than in late varieties, but this is not always the case. Some early kinds may have more straw than grain (type No. 3).

The variation in yield of grain and straw was also studied under different conditions of growth. Experiments were conducted, with thickly and thinly sown seed beds at different centres in the Province. It is no use recording the details here as nothing definite was found. Generally speaking, when close planting was practised one or two seedlings in one hole, gave the largest outturn, with wide planting more seedlings did well. Again thick coarse varieties with abundance of leafy growth do better at a distance of nine inches apart, while thin slender ones with less leaves give good results when some six inches apart. The optimum rate for number of seedlings in one hole and their distance apart seems different for different varieties and it seems to vary in different parts of the Province.

## 178. CLASSIFICATION &amp; STUDY OF CHARACTERS OF CULTIVATED RICES, U. P.

The relationship between the tillering and the yield and the height and the yield was studied. The following tables show the correlation of these factors :—

TABLE XXI.

*Showing correlation between tillering and yield.*

Strain No.	Mean No. of fertile tillers	Mean yield of grain per plant grm.	Co-efficient of correlation between tillering and yield per plant	REMARKS
25 . . . .	13.3	35.7	$0.87 \pm 0.01$	Correlation very close.
22 . . . .	8	26	$0.88 \pm 0.01$	Do.
1 . . . .	11.2	27.3	$0.64 \pm 0.03$	Correlation close.
7 . . . .	24.0	63.3	$0.91 \pm 0.01$	Do.
67 . . . .	215.1	89.2	$0.79 \pm 0.02$	Do.

50 observations were made in each case.

There is a close relationship between number of tillers and yield per plant within a strain. This is perhaps what might have been expected as yield is generally determined more by the number of fertile tillers than by any other factor.

TABLE XXII.

*Showing correlation between the height and yield per plant.*

Strain No.	Height in cm.	Yield per plant in grm.	Co-efficient of correlation	REMARKS
22 . . . .	116.8	26	$-0.16 \pm 0.06$	Correlation slight.
1 . . . .	112.0	27.3	$-0.16 \pm 0.06$	Do.
15 . . . .	155.0	62.3	$0.63 \pm 0.04$	Correlation close.
70 . . . .	133.5	92.7	$0.68 \pm 0.03$	Do.
67 . . . .	141.1	89.2	$0.32 \pm 0.06$	Correlation appreciable.

50 observations were made in each case.

The relationship like that of the height of the plant and the length of the main panicle seems to be negative in some and positive in others. The amount of correlation also appears to vary. In some strains it is slight, while in others it is appreciable (No. 67). The varieties showing close correlation are late in ripening. It has been observed that late ripening varieties are usually tall and are generally good yielders although it is not invariably so.

The yield of a plant is subject to great variation, depending as it does on the availability of plant-food and climatic conditions. Even variation of distance between plant to plant and the number seedlings in a hole also brings in differences in the yield. Obviously, therefore, a scheme of classification based on the character of the yielding capacity of plants would not be a very satisfactory one.

### 5. Sterility.

The habit of producing unproductive spikelets is a phenomenon of rather common occurrence in some rice varieties. It is closely connected with yield. The sterile ear-heads become quite white and feathery and do not produce any grains in them. Observations made during the course of five years' work on the rice crop in the United Provinces show that sterility is due to various causes. It may happen that only a few stray spikelets become sterile or the whole ear-head is affected. The former may be due to chance lack of fertilization, caused by unfavourable weather conditions, and the latter to the cutting of the food supply of the whole panicle from below and its drying up, caused by a stem-borer (*Schoenobius bipunctifer*). Its attack becomes severe in cases, where the crop is grown in rich well-manured fields. Sometimes in poor dry soils, when there is scarcity of water at the flowering season, the percentage of sterility also increases. This is probably due to a heat stroke. The most prevalent form, however, found in these provinces is the one caused by the borer.

A disease called "straight head", which resembles very much the sterility of the ear-head, is reported from America. A detailed account of it is given by Messrs. Tisdale and Jenkins.<sup>1</sup> According to them it is not known yet whether this is a disease or a condition brought about by physical causes. They say that the presence of organic matter in certain stages of decay produces a condition of soil that allows more water to be taken in and this tends to press out the air to such an extent that the root system fails to develop normally, thus disturbing the nutrition of the plant, which produces "straight head." The remedy for this, according to them, consists in draining the land and irrigating for about 10 days after the plants emerge. According to Bhide,<sup>2</sup> sterility is not always due to unfavourable environment but it may be a hereditary quality. Bhide's assertion seems quite probable as it has

<sup>1</sup> Tisdale, W. H., and Jenkins, J. M. "Straight head" of rice and its control. *United States Dept. Agri. Farmers Bull.* 1912.

<sup>2</sup> Bhide, R. K. A cause of sterility in rice flowers. *Agri. Jour. India*, Vol. XVII, Nov. 1922, p. 584.

been observed that it is only certain types which are more susceptible to it than others. The character, being closely allied to yield, is not an important one from a classification point of view.

#### 6. *Spikelet.*

The spikelets are articulated on the pedicles and each has a set of four glumes, the two outer sterile or empty glumes, and the two inner fertile or flowering glumes enclosing the grain.

(a) *Outer glumes.* (Plate II, 3). These are usually small, hard and shiny. In one variety called *Suapankhi* (Plate IV, 2) they are large, almost equalling or exceeding the spikelet in size. The colour is usually white, and somewhat paler than the inner glumes. It bears no relation to the colour of the inner glumes. The outer glumes may be purple, while the inner glumes are colourless (common colour) and *vice versa* (Table VIII). The colour of the outer glumes when present generally gets faint near ripening. These colours are fairly constant and are useful in distinguishing different varieties from one another.

(b) *Inner glumes.* (Plate II, 3). These are two in number enclosing the rice grain, one being bigger and five-nerved and the other narrower and three-nerved. The most common colour is pale yellowish white. Other colours are red, orange, brown, purple and black, each including many shades. Sometimes a mixture of one or two of these colours on one spikelet gives a pibald appearance to the grain. The ridges and grooves, so common on these inner glumes, occasionally show difference of colour on them. The ridges are generally paler in colour than the grooves. These ridges are more prominent in coarse spikelets than in slender ones. The colour of inner glumes is fairly constant, and is a useful diagnostic character.

(c) *Awn.* This, when present, is the prolongation of the tip of the inner, bigger glume. It is a hard bristle-like structure of varying length and colour. Awns are generally found in coarse types. (Table XXIII). Wild uncultivated types and usually those grown in swamps also show abundant production of awns (Plate I, 2). In the United Provinces, the progression in value is from the awned to the awnless and from the coloured to the colourless varieties. Kikwa<sup>1</sup> also states that most of the prevalent varieties in advanced centres of rice culture are awnless. In certain localities, e.g., near the *turai* (a belt at the foot of the Himalayan Mountains) awned varieties are preferred to the awnless, as the presence of awns protects the crop from the attacks of pigs and other wild pests. No feature is more variable among the rices grown in these Provinces than the awn character. The length varies in different varieties and even within the same variety; the length of the awn is by no means constant. Ordinarily it varies from a tiny little bristle to a maximum of three inches. In many cases awns appear only on a few spikelets near the tip of the ear-head, the basal spikelets remaining awnless. In fact, it is very

<sup>1</sup> Kikwa, S. *ibid.*, p. 19.

difficult to determine in some cases, whether a spikelet is awned or awnless, as there may be just the faintest trace or suspicion of an awn, yet it is so small as not to be measurable. Out of a total of 135 varieties classified here, only 43 possess awns. Of these, five are broadcast, fifteen are transplanted early ripening and the remaining 23 are transplanted late ripening varieties. The most common colours met with are light yellow, red and black purple. Yellow generally fades away and appears white and the purple, if it is intense, becomes reddish brown near maturity. The awn character, as represented in a few typical kinds in these Provinces, is shown in Table XXIII.

TABLE XXIII.

*Awn character of the rices of the United Provinces.*

Strain No.	Length of awn in inches	COLOUR OF		Character of rice (hulled grain)
		Awn	Apiculus	
<i>Broadcast varieties—</i>				
132 . .	Tiny bits to 1.5" .	black .	purple when young, black when ripe.	Bold coarse.
131 . .	Tiny bits on stray spikelets near the tip only.	Do. .	Do.	Coarse.
133 . .	Tiny bits to 1.5" .	white .	no colour . .	Do.
130 . .	Tiny bits to 2.5" .	brown .	dull brown . .	Do.
<i>Transplanted varieties—</i>				
<i>Early</i> 39 . .	5" to 2" . .	deep purple	deep purple . .	medium coarse.
63 . .	1" to 3" . .	Do. .	Do. . .	Coarse.
114 . .	Tiny bits to .5" .	white .	no colour . .	Do.
50 . .	Tiny bits to 1" .	Do. .	Do. . .	Do.
<i>Late</i> 37 . .	.5" . . . .	Do. .	Do. . .	Do.
23 . .	.5" to 1" . .	orange brown.	dull orange red .	fine.
127 . .	.5" to 2" . .	white .	black purple . .	medium coarse.
15 . .	.5" to 1.5" . .	black purple	Do. . .	bold fine.
45 . .	.1" to .5" . .	Do. .	black . . .	medium coarse.

The black or red purple colour is present only in cases where the apiculus or the spikelet has also the same colour. It is, however, not always necessary, that it should have simultaneous colouring with the apiculus. It may be white when the apiculus is black purple (No. 127). Beale<sup>1</sup> states that the presence of awns is dominant to absence of them, and they show Mendelian segregation in splitting. The character, being variable, is not of much use in the present scheme of classification.

(d) *Clustered spikelets*. (Plate IV, 1). The spikelets are usually solitary, but in type No. 75 from Shahjahanpur district, popularly known as *Gunchai* spikelets, are clustered together in groups of two to five. The branches, by this clustering together, show a slightly interrupted appearance. There are only two such varieties, in which this character is found in these Provinces and it is therefore not of much importance in the scheme of classification.

(e) *Winged spikelets*. (Plate IV, 2). The sterile outer glumes of the common cultivated rices are usually small, and their length is less than one-third of the flowering or the fertile glumes. A few rices, however, e.g., *suapankhi* (No. 74) from Sitapur district have very long empty glumes, the length of which may equal or even exceed that of the flowering glumes. Such rices have a characteristic winged appearance and though it is an interesting phenomenon from the systematic standpoint, the character is limited only to two rices in the United Provinces and is therefore of not much importance. According to S. Tanaka quoted by Kikwa<sup>2</sup>, these long glumed rices are considered by farmers in Japan to be more resistant against the injury of winds than common rices. The rices being inferior and coarse in nature and the character being not common, this question has not received much attention here. The feature is not of any economic value, because such winged and awned varieties are not appreciated by the traders as the proportion of the kernel in a measure of such grain is low and one gets bulk without weight.

(f) *Number of spikelets*. The number of spikelets on a single ear-head is usually large in types possessing short round shape of spikelets and less in those possessing long slender-shaped spikelets. The maximum number of 600 to 650 is found in *samhera* (No. 66) from Unao district and the least of 80 to 90 in early broadcast *sathi* (No. 132) which is universally grown all over the Province. In slender fine rices, e.g., *bansmati* (No. 3) from Dehradun, and *kala Sukhdas* (No. 23) from Banda, it ranges from 150 to 300. Generally speaking, late ripening kinds have a greater number than the early ripening, and broadcast types. (Table XI). There seems to be a close relationship between the number of branches and the number of spikelets on the ear-head. This is shown in Table XXIV.

<sup>1</sup> Beale, R. A. *ibid.*, page 13.

<sup>2</sup> Kikwa, S. *ibid.*, p. 22.

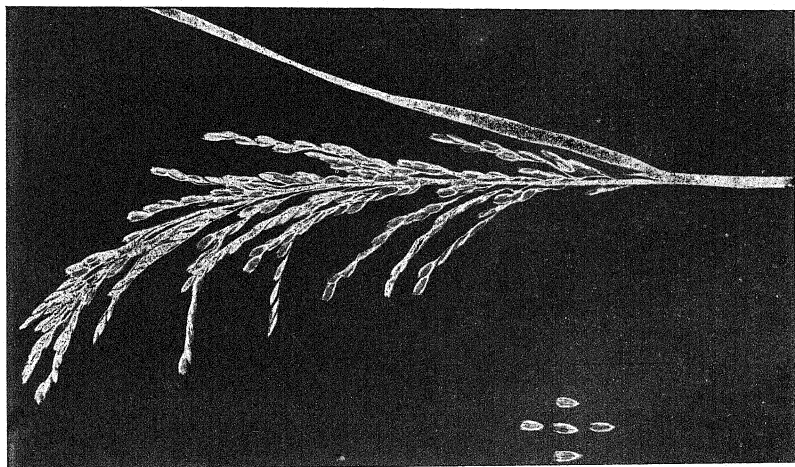


Fig. 2. Winged spikelets.



Fig. 1. Clustered spikelets

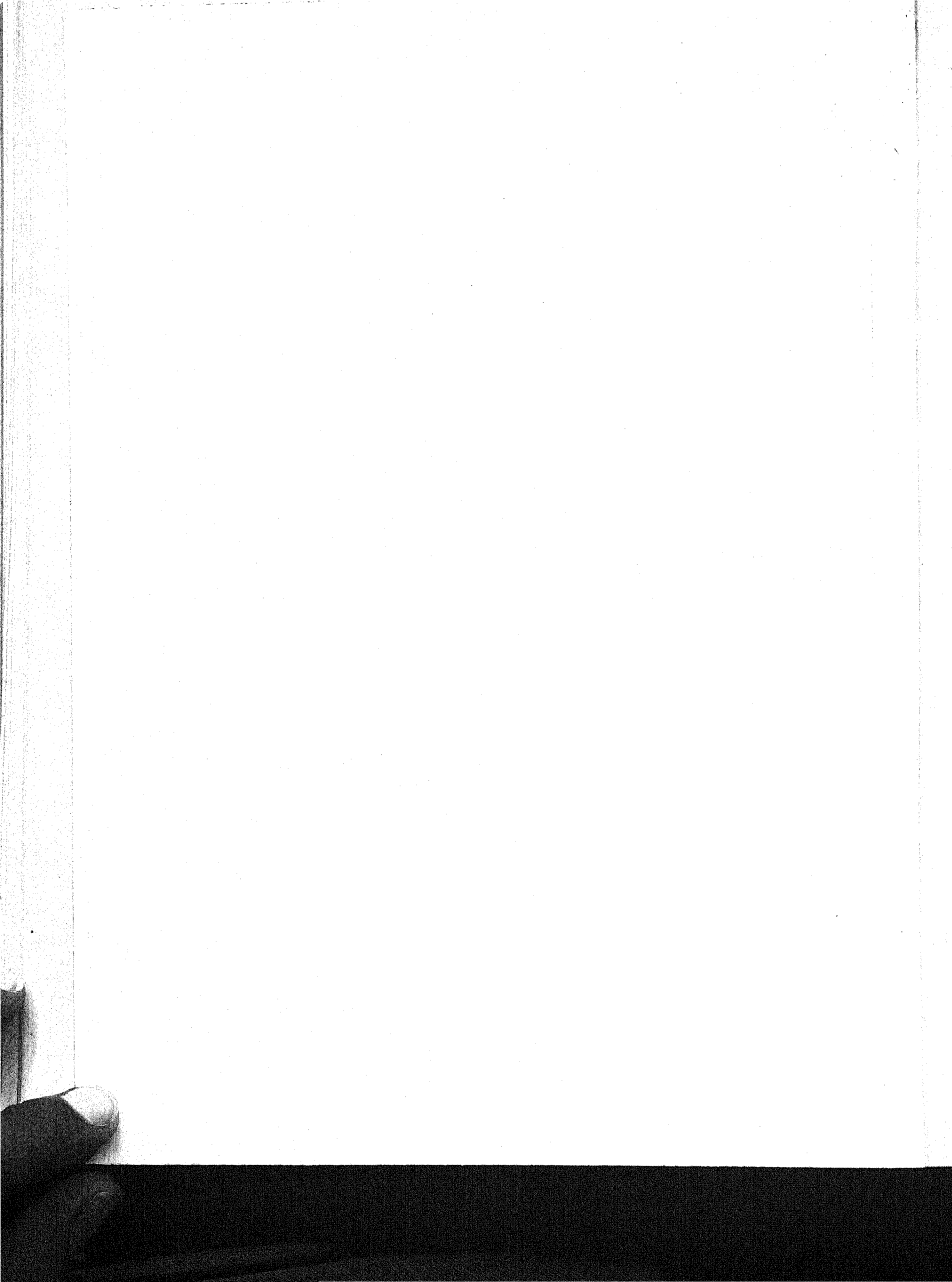


TABLE XXIV.

*Showing correlation between number of branches and number of spikelets in the main panicle.*

Strain No.	Mean No. of branches	Mean No. of spikelets	Co-efficient of correlation between branches and spikelets	REMARKS
22 . . . .	15.4	172	$0.78 \pm 0.02$	Correlation close.
23 . . . .	13.8	187	$0.69 \pm 0.03$	Do.
25 . . . .	14.5	165	$0.65 \pm 0.03$	Do.
1 . . . .	14.7	209	$0.69 \pm 0.03$	Do.
67 . . . .	16.9	244	$0.71 \pm 0.03$	Do.

50 observations were made in each case.

The relationship between tillering and the number of spikelets is also shown in Table XXV.

TABLE XXV.

*Showing correlation between tillering and number of spikelets in the main panicle.*

Strain No.	Mean No. of tillers	Mean No. of spikelets	Co-efficient of correlation between tillering and spikelets	REMARKS
23 . . . .	8.5	187	$0.08 \pm 0.06$	Correlation negligible.
1 . . . .	11.2	209	$0.09 \pm 0.06$	Do.
25 . . . .	13.3	165	$0.12 \pm 0.06$	Correlation slight.
22 . . . .	8	172	$0.45 \pm 0.05$	Correlation fairly close.
67 . . . .	25.1	244	$0.05 \pm 0.06$	Correlation negligible.

50 observations were made in each case.

The amount of correlation within each pure strain varies much. In some it is negligible, while in others it is fairly close.

(g) *The weight of the spikelets.* The finer rices weigh lighter than the coarse ones. The weight of spikelets from about 200 heads of a coarse type lay between 300 to

400 gram, while a similar number of heads of a fine rice weighed between 150 to 250 gram. The weight of the ordinary commercial rices of the United Provinces per 100 grains in the three typical representative groups is as follows :—

- |                                   |  |
|-----------------------------------|--|
| 1. Broadcast coarse 2.4 gram.     | } The figures in each case represent the average of six varieties. |
| 2. Transplanted fine 2.11 gram.   |  |
| 3. Transplanted coarse 2.58 gram. |  |

According to Copeland,<sup>1</sup> it is 2.0 gram. per 100 grains of the ordinary commercial rices in the Philippines. The following Table shows the relation between the weight of the panicles and the tillers.

TABLE XXVI.

*Showing correlation between number of tillers and the weight of an average panicle.*

Strain No.	Duration	Mean No. of tillers	Mean wt. of average panicle gram.	Co-efficient of correlation between tillering and yield per average panicle	REMARKS
22 . .	late . .	8	3.36	0.51 ± 0.05	Correlation fairly close.
23 . .	do. . .	8.5	2.92	-0.11 ± 0.06	Correlation slight.
1 . .	early . .	11.2	2.5	-0.41 ± 0.05	Correlation fairly close.
25 . .	late . .	13.3	2.68	0.01 ± 0.06	Correlation negligible.
70 . .	v. late . .	22.0	4.21	-0.59 ± 0.04	Correlation fairly close.

50 observations were made in each case.

The amount of correlation appears to vary much. In some strains, it hardly exists or is negligible as in strain No. 25 and No. 23. In others, *e.g.*, in No. 1, 22 and No. 70 it is fairly close. The correlation also between the number of tillers and the yield of grain, per average panicle within each pure strain, has been found to be negative in the majority of cases.

(h) *Size of the spikelets.* The spikelets may be divided into three groups according to their size. "Slender" spikelets in which the length is thrice or more than

<sup>1</sup> Copeland, E. B. *Rice*. (New York, 1924).

three times the breadth, "long" in which length is more than twice the breadth but less than thrice and "short" when length equals twice or is less than twice the breadth. No grain is found in these Provinces in which the length is less than 1.4 times the breadth. The size of the grain may also be expressed by its three dimensions as large, medium and small and as the thickness of the grain of a certain shape does not show such considerable difference as its other two dimensions, (*i.e.*, length and breadth) the measurement of length and breadth can show the relative size of a grain with tolerable accuracy. The division of rice according to their sizes is very useful economically, as different sizes have different values and uses in these Provinces. The character has therefore been employed as one of the main heads in the present scheme of classification.

(i) *Grain (Kernel)* (i) *Size*. The size of the kernel corresponds approximately to the size of the spikelet and the grain may therefore be allowed to fall into the same groups in which the spikelets are placed. The length of the grain of a slender spikelet is thrice or more than three times the breadth, of a long spikelet is more than twice the breadth and of a short one equals twice or is less than twice the breadth.

(ii) *Colour of the kernel*. According to the colour of the kernel, the rice falls into two groups, the first which is by far the commonest in the United Provinces is of white rice, while the second contains coloured rice. The colour in white varieties forms almost a chalky white to a translucent waxy white, sometimes with pale yellowish or greenish tint, while among the coloured rice it varies from light to deep red. No black coloured kernel is found in these Provinces. The colour of the kernel has no relation with that of the spikelet colour (Table VIII). We may get different combinations such as:—

1. Husk white, kernel red, *e.g.*, Type No. 114 *Chamba* awned from Saharanpur.
2. Husk white, kernel white, *e.g.*, Type No. 18 *Maldehi* awned from Unao.
3. Husk coloured, kernel red, *e.g.*, Type No. 119 *Lohni* from Jaunpur.
4. Husk coloured, kernel white, *e.g.*, Type No. 63 *Lalsar* from Gonda.

The grains of a plant are all white or all red. One does not come across the ears of the same plant, some having red and others white grains. The colour is contained in the pericarp and is removed in the process of polishing rice. According to Mitra,<sup>1</sup> redness of the kernel is dominant to whiteness and on crossing these segregate according to the Mendelian ratio. The mixture of coloured rice with the white ones spoils the market value of the latter. The classification of rice, according to the colour of their grain, is thus of considerable importance, as besides being a constant character, its presence or absence is of sufficient economic value in trade. The character has therefore been employed as the main head in the present scheme of classification.

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<sup>1</sup> Mitra, S. K. *ibid.*, p. 100

### 7. *Scheme of classification.*

Before giving the scheme we may summarize the various reasons for employing the characters of grain as the basis of the present scheme of classification. These are as follows :—

(1) The characters of the grain are more constant than, and not subject to such environmental influences as, the vegetative and the agricultural characters discussed before. The use of agricultural characters in a scheme of classification demands a considerable amount of caution. In a large area like the United Provinces with markedly different climatic conditions, where different systems of cultivation are in vogue, no hard and fast system of classification based either on vegetative or agricultural characters could be laid down.

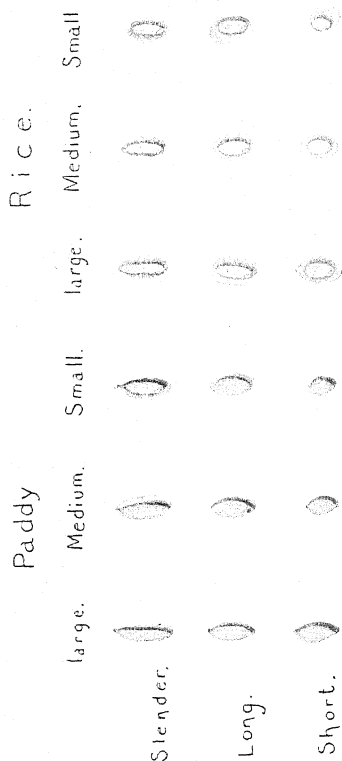
(2) Red grain is generally disliked and is considered inferior to the white one. Its admixture spoils the market value of white rices. Moreover, to get rid of red colour entirely, much labour is required in milling and also a considerable percentage of the outer farinaceous portion of the grain is lost. The classification of rices according to the colour of the grain is thus of considerable importance.

(3) A general preference is shown for rices which have a slender grain. Slenderness is an essential quality for a rice to be counted as fine and this commands a large price in the market. Slender rices occupy a very important position in trade, either internal or foreign. The sizes, slender, long and short, signify the expensiveness of the grain. The grouping of varieties thus according to the size of their grain has the advantage of classifying them according to their use in trade.

(4) Rices are generally bought and sold on the character of the size of the grain. Slender rices are considered the best table rices in the United Provinces, big bold and coarse rices are generally fried and are sold as such, while short round and medium types are consumed locally by poor classes. The classification according to size of the grain is thus very useful from the point of view of their general use and taste.

Careful measurements of the length, the breadth and the thickness of the grain, with and without husk, were made with the help of a simple micrometre. These measurements along with the calculation of the ratio between the length and the breadth of the hulled grain have been employed for grouping the varieties and invariably enable one to determine the class to which a particular rice rightly belongs. It may be observed in the synopsis given below that there is overlapping in various measurements of lengths and breadths between different groups, but it will be found that the ratios between length and breadth do not overlap in any case. The grouping has been arranged according to these ratios. Experience shows that the ratio is a better means of distinguishing one group from another than the length or the breadth alone, as it gives one the idea of the shape of the grain as well. Thus any variety, the grain of which has dimensions and ratios lying between the limits shown in the scheme given below, may be said to belong to that group.





Paddy and rice grains showing the range of different groups of classification

(Natural size)

CONSPICUOUS OF CLASSIFICATION (HULLED GRAIN) (PLATE V).

Division I. White Grain.

	Type Nos	Total
Group A.— <i>Slender Grained.</i> When the length is thrice or more than three times the breadth—		
(i) <i>large</i> length 7.3 to 7.9; breadth 1.7 to 1.8; length is more than 4 times the breadth . . . . .	1 to 3	(3)
(ii) <i>medium</i> length 6.6 to 7.4; breadth 1.7 to 1.9; length is over 3.5 to 4 times the breadth . . . . .	4 to 11	(8)
(iii) <i>small</i> length 5.2 to 7.4; breadth 1.7 to 2.4; length is 3 to 3.5 times the breadth . . . . .	12 to 33	(22)
Group B.— <i>Long Grained.</i> When length is more than twice the breadth but less than thrice—		
(i) <i>large</i> length 5.4 to 7.4; breadth 1.8 to 2.5; length is over 2.6 to 2.9 times the breadth . . . . .	34 to 54	(21)
(ii) <i>medium</i> length 4.8 to 6.7; breadth 1.9 to 2.6; length is over 2.3 to 2.6 times the breadth . . . . .	55 to 67	(13)
(iii) <i>small</i> length 4.2 to 6.3; breadth 1.9 to 2.8; length is over 2 to 2.3 times the breadth . . . . .	68 to 82	(15)
Group C.— <i>Short Grained.</i> When length equals twice or is less than twice the breadth—		
(i) <i>large</i> length 4.0 to 5.6; breadth 2.0 to 2.9; length is over 1.8 to 2 times the breadth . . . . .	83 to 99	(17)
(ii) <i>medium</i> length 4.4 to 5.4; breadth 2.6 to 2.9; length is over 1.6 to 1.8 times the breadth . . . . .	100 to 103	(4)
(iii) <i>small</i> length 3.6 to 4.4; breadth 2.2 to 2.9; length is 1.4 to 1.6 times the breadth . . . . .	104 to 110	(7)

Division II. Coloured (Red) Grain.

Group A.— <i>Slender Grained.</i> When length is thrice or more than three times the breadth—		
(i) <i>large</i> None . . . . .		<i>Nil</i>
(ii) <i>medium</i> None . . . . .		<i>Nil</i>
(iii) <i>small</i> length 6.0 to 7.2; breadth 1.8 to 2.1; ratio Do as in white grain . . . . .	111 to 112	(2)
Group B.— <i>Long Grained.</i> When length is more than twice the breadth but less than thrice—		
(i) <i>large</i> length 5.85 to 7.1; breadth 2.01 to 2.5; ratio Do as in white grain . . . . .	113 to 116	(4)
(ii) <i>medium</i> length 5.8 to 6.2; breadth 2.2 to 2.5; ratio Do as in white grain . . . . .	117 to 120	(4)
(iii) <i>small</i> length 5.1 to 6.1; breadth 2.2 to 2.7; ratio Do as in white grain . . . . .	121 to 128	(8)
Group C.— <i>Short Grained.</i> When length equals twice or is less than twice the breadth—		
(i) <i>large</i> length 4.5 to 5.2; breadth 2.2 to 2.6; ratio Do as in white grain . . . . .	129 to 131	(3)
(ii) <i>medium</i> length 3.74 to 2.2; breadth 2.23 to 2.9; ratio Do as in white grain . . . . .	132 to 135	(4)
(iii) <i>small</i> None . . . . .		<i>Nil</i>
Total Nos. . . . .		(135)

The measurements and important physical properties of the unhulled and hulled grains of 135 varieties of the United Provinces, which the writer has examined and classified according to the above standards, are shown in the Table in the Appendix. Out of a total number of about one thousand samples which reached the author's hands from various parts of the Province as distinct varieties, and included almost all the available types, only 135 varieties have been isolated by successive growth, as pure types, possessing constant characters. Thus the actual number of pure types cultivated in these Provinces is much smaller than what is generally supposed. A few stray types may have been missed out here and there, because sometime fresh kinds keep coming into the Province from Nepal territory and other adjoining areas of the Champaran districts and the Punjab. These are difficult to include till they are grown on a sufficiently large area for a number of years, and are considered permanently belonging to the Province. The lists classified include almost all common established varieties cultivated in different parts of the Province for a number of years.

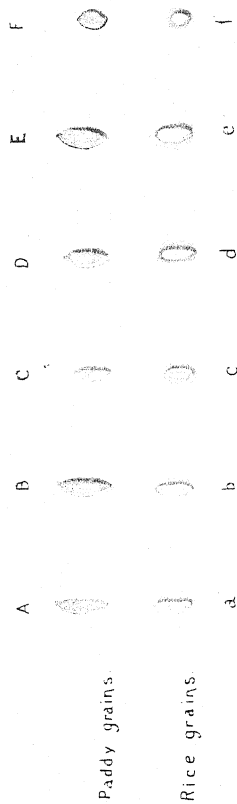
It is also important to measure the average volume of grains, because the size of the grain is most accurately expressed by its volume. These volumes are also given in the Table in the Appendix. The following Table shows how the product of the length by breadth of the hulled grains harmonizes with its real volume in average of different forms of which the length, the breadth and the volume are measured.

TABLE XXVII.

*Showing the relation between the product of the length by breadth and the volume (hulled grain).*

Size of the grain		No. of varieties averaged	Average length mm.	Average breadth mm.	Product of L x B	Volume of 1,000 grain c.c.	Quotient of L x B ÷ Vol.
Slender	large	3	7.57	1.76	13.32	12.03	1.105
	medium	8	6.02	1.87	12.94	12.62	1.022
	small	24	6.66	2.07	13.78	13.14	1.048
Long	large	25	6.36	2.26	14.37	13.50	1.064
	medium	17	5.86	2.32	13.59	12.74	1.066
	small	23	5.66	2.55	14.43	13.63	1.058
Short	large	20	5.03	2.52	12.67	12.20	1.038
	medium	8	4.82	2.70	13.01	13.00	1.000
	small	7	4.07	2.63	10.70	9.91	1.076





Different shapes of Paddy and rice grains found in the United Provinces  
(Natural size)

8. *The shape of hulled and unhulled grain (Plate VI).*

Broadly speaking, there are six distinctive shapes found in the United Provinces. These are shown as A B C D E F in the case of unhulled grain and a b c d e f in the case of hulled grain respectively. In shape also the hulled grain usually follows the spikelet and may, therefore, be allowed to fall into the same classes in which the spikelets are placed. The long-grained rice is much more easily broken than the short-grained in the hulling and polishing operations and the rice mixed with broken grain cannot be boiled uniformly. It is for these reasons that long-grained rice, which is a popular table rice, is expensive if it is to be prepared free from broken grains. As the shape also has some connection with the process of polishing and taste, such distinction is therefore useful. The distinctive shapes of various varieties have been assigned to them in the Table in the Appendix.

The different varieties representing these shapes are as follows :—

TABLE XXVIII.

*Showing different shapes of grains.*

Variety	District	SHAPE OF		REMARKS
		unhulled grain	hulled grain	
<i>Ramjivrai</i> (No. 1)	Saharanpur	A	a	
<i>Chaul</i> (No. 21)	Rampur	B	b	
<i>Anjee</i> (No. 26)	Gorakhpur	C	c	
<i>Somlhi</i> (No. 43)	Etah	D	d	
<i>Sonesari</i> (No. 72)	Sitapur	E	e	
<i>Ramjai</i> (No. 110)	Allahabad	F	f	

The following description will elucidate further points about different shapes :—

- A. It may be called as *fine*. It is a long slender grain of fine appearance, shape linear, apiculus very prominent and often curved. Kernel translucent.
- B. It may be called as *bold fine*. It is a long slender grain but bolder and broader than A. Shape lanceolate. Apiculus prominent but often straight. Kernel translucent.
- C. It may be called as *medium fine*. It is usually slender grain of linear shape but it is of medium size and is shorter in length than A. Apiculus prominent, straight or curved. Kernel translucent.

- D. It may be called as *medium coarse*. It is a short medium grain, broader and coarser than C. Shape obliquely obovate. Apiculus prominent often straight. Kernel usually translucent, sometimes with a chalky deposit of abdominal white.
- E. It may be called as *bold coarse*. Large broad grain of bold coarse nature. Shape broadly elliptic. Apiculus end usually round with a beak. It is the boldest of all the types. Kernel usually showing chalky deposit of abdominal white.
- F. It may be called as *round*. Short bold grain of round shape. Apiculus end round; abdominal white well developed and the grain often appears opaque.

The varieties of class A are mostly cultivated in the western part of the Province where irrigation is practised. Some of them are fragrant and are the most popular table rices. They are consumed locally by rich people and are chiefly exported to the Punjab and other adjoining areas. When milled in an ordinary way, they give a product of fine appearance which is highly esteemed, but owing to their length and slenderness the breakage is very high. In order to overcome this defect, the parboiling process is usually adopted.

Class B is milled either by parboiling or in ordinary way. The varieties of this class are better yielders than class A and go generally to the same markets. They are grown scattered all over the Province.

Class C and D comprise by far the largest number of varieties and cover the largest area in the United Provinces. They are mostly consumed locally and are exported to Bombay, Bihar, Central Provinces and other adjoining areas. They constitute the most important class because of their universal cultivation all over the Province. The varieties are very mixed and red grain are common.

Class E is probably second to class C and D as regards area under cultivation. Being bold and coarse, their use is different. They are generally fried and are sold as such. The trade in this rice is mostly local.

The varieties of class F are few in number. They are generally very good yielders and are more tasty. Because of well developed abdominal white, the milled product appears chalky.

With regard to the utility of the grain, the rices may also be divided into the following two groups :—

#### 9. (a) *Glutinous and Non-glutinous rice.*

The grain of the glutinous rice, when dried, becomes quite opaque, and its endosperm shows a chalky white colour, as compared to the non-glutinous, which has a clear translucent grain. When the grain is cut into two, the former shows a dull white surface and is soft in nature, while the latter is hard and shows a translucent surface. The soft glutinous rice forms a sticky mass when cooked, while

the hard non-glutinous rice retains each kernel separate and is therefore considered to be of much better quality. Non-glutinous rice also mills better and stands shipment better than the glutinous. Economically the former is therefore more important than the latter. Kikwa,<sup>1</sup> says that in Japan the use of glutinous rice is quite different from that of the non-glutinous rice. No example of glutinous rice has been found in the United Provinces and the work therefore is confined to the non-glutinous rices only.

#### 9. (b) *Scented and ordinary rice.*

Some varieties of the rices of the United Provinces possess flavour and fragrance in the grain as well as in the plant. The typical examples are *bansmati* (No. 3) from Dehradun and *kalasukhdas* (No. 23) from Banda. Their fragrance is strong from about 20 days after transplanting to the flowering time in the field, and then afterwards in the grain, while cooking. The fragrant rices have always been valued so much that according to Watt, as quoted by Kikwa,<sup>2</sup> a few fields of strongly scented-rice grown opposite the fort of Bara near Peshawar (N. W. F. P.) are watched for reserving the produce for the Kabul Sirdars. In the United Provinces, *bansmati* is a famous table rice, and its popularity is chiefly due to its fineness of grain, and its fragrance. The scented rices are held in high esteem throughout the Province and have a better market value. They deserve to be grouped by themselves, but the number is very few and the varieties being expensive, their demand is limited. It is therefore not worth having this character as the main distinction for classification.

Two more characters of the grain deserve mention. These are as follows :—

#### 10. *Double grains.*

Some varieties of rice are said to contain more than one ovary in a spikelet. Graham<sup>3</sup> reports two such kinds in the Central Provinces. Such varieties have been referred to by Col. D. Prain<sup>4</sup> as *Oryza Sativa* var *Plena*. This ranks as a systematic variety like the rices with clustered spikelets, but the writer has had no opportunity of examining any specimen of such rice in the United Provinces.

#### 11. *Abdominal white.*

In the middle ventral side of the grain of the non-glutinous rice, there exists a chalky white portion which is called abdominal white. According to Kikwa,<sup>5</sup>

<sup>1</sup> Kikwa, S. *ibid*, p. 23.

<sup>2</sup> Kikwa, S. *ibid*, p. 27.

<sup>3</sup> Graham, R. J. D. *ibid*, p. 228.

<sup>4</sup> Prain, D. *Bengal plants*, p. 1184.

<sup>5</sup> Kikwa, S. *ibid*, p. 29.

is exists in the glutinous rice also, but as the endosperm of the glutinous rice is uniformly chalky-coloured, it is impossible to distinguish the abdominal white, and is therefore not spoken of with this group of rice. S. Tanaka quoted by Kikwa states that the abdominal white results from the insufficient supply of nutritive matters to the grain at the ripening time. It is therefore an indication that a grain is immature and that the carbohydrate has not been converted into its most concentrated form. It generally occurs only slightly or is entirely absent in slender grains, and is often conspicuous in short and bold types of rices. Kikwa distinguishes between different types of abdominal white. It is rather difficult to make out the distinction of this character between different rices found in the United Provinces and its presence or absence in a portion of the endosperm as a basis for classification has nothing very much to recommend it.

My thanks are due to M. Kabir Khan, member, Subordinate Agricultural Service, for the help rendered in the collection of varieties and for careful cultivation of various experimental plots required for this study during the course of six years.

## V. APPENDIX.

Cultivated rices of the United Provinces measured and classified according to the size and shape of the hulled grain.

*Abbreviations.*

E	.	.	.	Early.
M	.	.	.	Medium.
L	.	.	.	Late.
V. L	.	.	.	Very late.
c	.	.	.	Common colour (Pale yellowish white).
b	.	.	.	Brown or brownish.
p	.	.	.	Purple.
bl.	.	.	.	Black.
r	.	.	.	Red
y	.	.	.	Yellow.
w	.	.	.	White.
o	.	.	.	Orange.
l	.	.	.	Light.
d	.	.	.	Deep.
dl	.	.	.	Dull.
t	.	.	.	Tiny bits of awns in some stray spikelets ; more near the tip of the ear-head.

Type No.	Popular name	District	UNHULLED GRAIN									
			Duration	Length m/m	Breadth m/m	Thickness m/m	Length of awns in inches	Shape	COLOUR OF			
									Outer glumes	Inner glumes	Awns	Aplous
WHITE GRAIN												
(a) SLENDER												
(i) Large												
1	Ranjitwala	Dehradun	B	9.78	2.02	1.74	..	A	w	l. o	..	r. p
2	Safed munji	Saharanpur	B	10.24	2.00	1.69	..	A	l. p	e	..	r. p
3	Danemati	Dehradun	B	9.78	1.98	1.79	..	A	w	e	..	d. y
(ii) Medium												
4	Jarhan	Saharanpur	M	9.40	2.02	1.76	t	A	w	e	p	bl.
5	Hansraj	Gonda	V. L	9.54	2.18	1.86	..	A-B	w	e	..	..
6	Mushkan	....	E	9.82	2.16	1.76	t	A-B	w	dl. br	p	d. p
7	Bansphool	Fyzabad	E	8.60	2.00	1.66	..	A	w	e	..	..
8	Dhan Gorakhpuri	Garhwal	E	9.16	1.90	1.67	..	A	w	d. o	..	..
9	Duniapat	Basti	L	9.25	2.10	2.04	..	A-B	w	e	..	o
10	Hansraj	Cawnpore	L	8.88	2.02	1.76	*5"-2.5"	A-B	l. p	dl. o. r	r. p	d. b
11	Duniapat	Basti	L	9.15	1.95	1.76	..	A-B	w	l. o	..	bl. p
(iii) Small												
12	Hansraj	Unao	E	9.80	2.24	1.92	..	A-B	w	e	..	..
13	Jarhan	Muzaffarnagar	E	8.75	2.01	1.62	*5"-2"	A-C	w	o. b	w	..
14	Ranikajar	Etah	B	9.82	2.23	1.90	t	A-B	p	e	p	bl.
15	Jarhan	Barabanki	L	10.15	2.33	1.90	*5"-1.5"	B	r. p	e	bl. p	bl. p
16	Parjati bara	Sitapur	L	9.27	2.28	1.93	t	B	r. p	dl. bl. p	p	bl.
17	Bansi	Allahabad	L	9.92	2.22	1.85	..	A-B	w	l. o	..	..
18	Maldehi (awned)	Unao	E	8.75	2.00	1.77	*5"-2"	A-B	w	e	w	..
19	Danemati	Garhwal	E	8.78	2.13	1.77	t	A-B	w	e	d. b	d. b
20	Basbati	....	E	9.40	2.08	1.76	..	A-B	w	e	..	dl. o



Type No.	Popular name	District	UNHULLED GRAIN									
			Duration	Length m/m	Breadth m/m	Thickness m/m	Length of awns in inches	Shape	COLOUR OF			
									Outer glumes	Inner glumes	Awns	Apiculus

## WHITE GRAIN

## (a) SLENDER

## (H) Small

21	Chaul . . .	Rampur state .	E	10-08	2-33	1-94	..	B	w	c	..	..
22	Bansi . . .	Banda .	L	9-30	2-23	1-80	..	B	w	c	..	l. o
23	Kala sukhdas .	Banda .	L	9-38	2-15	1-77	5"-1"	A-B	p	dl. o. r	o. b	..
24	Bataswa . . .	Nainital . .	E	9-26	2-46	1-96	..	B	w	c	..	..
25	Parjati . . .	Sitapur . .	L	9-76	2-43	1-95	5"-1"	B	l. r. p	b. r	p	p
26	Anjee . . .	Basti . . .	L	7-86	1-94	1-65	..	C	w	c	..	..
27	Narma . . .	Farrukhabad .	E	9-90	2-55	1-93	5"-3"	B	w	l. o	l. b	..
28	Gond . . .	Jhansi . . .	E	10-22	2-53	2-00	..	B	d. p	dl. b. r	..	d. p
29	Jhona or chittah-moonjee.	....	E	9-78	2-38	1-91	..	B	w	c	..	..
30	Sakkarcheeni .	Banda . . .	E	8-26	2-20	1-78	tiny bits to 5"	B-C	d. p	dl. c	d. p	bl. p
31	Kajra . . .	Fatehpur . .	E	8-48	2-19	1-74	do.	B-C	r. p	y. r	r. p	bl.
32	Masino . . .	Nepal border .	L	8-36	2-24	1-84	t	B-C	w	c	w	b
33	Anjee . . .	Basti . . .	V. L	7-25	1-90	1-59	..	C	w	c	..	p

## (b) LONG

## (I) Large

34	Gulba'la . . .	Allahabad . .	L	10-61	2-65	1-99	5"-1"	R-D	w	c	w	..
35	Shiamzeera . .	Sitapur . . .	L	9-55	2-84	2-06	tiny bits to 5"	B-D	bl. p	dl. bl. p	p	bl.
36	Jayhan . . .	....	L	10-06	2-57	2-03	..	B-D	w	c	..	r. p
37	Sukhdas . . .	Allahabad . .	L	9-9	2-28	1-95	tiny bits to 5"	B-D	w	l. o. r	w	..

DIX—*contd.*

HULLED GRAIN												REMARKS
WEIGHT OF		Specific gravity	Length m/m	Breadth m/m	Thickness m/m	PROPORTION BETWEEN		Shape	Volume of 100 grains c. c.	Weight of 100 grains in gram	Specific gravity	
One plant produce in grm.	100 grains in gram					Breadth and length	Thickness and breadth					

WHITE GRAIN—*contd.*

(a) *Slender—contd.*

(iii) *Small—contd.*

33-60	2-962	1-181	7-28	2-22	1-73	3-2	1-28	b	1-38	1-962	1-436	-672	
56-55	2-392	1-190	6-94	2-14	1-65	3-2	1-29	b	1-47	2-025	1-347	-846	Inner glumes show light brown colour near ripening.
40-45	2-175	1-116	6-75	2-10	1-63	3-2	1-29	a-b	1-33	1-775	1-333	-816	Fragrant variety. The colour on inner glumes is more intense on the outer side.
39-02	2-807	1-211	6-95	2-22	1-79	3-1	1-24	b	1-50	2-114	1-405	-753	Inner glumes show brown markings in furrows, in early stages of growth.
71-00	2-860	1-102	6-66	2-22	1-76	3-1	1-26	b	1-95	2-510	1-282	-877	Inner glumes show more intense colour on the outer surface.
44-8	1-500	1-151	5-65	1-77	1-50	3-1	1-18	c	-88	1-105	1-345	-796	
39-10	3-165	1-143	7-20	2-37	1-76	3-0	1-34	b	1-54	2-235	1-446	-706	Inner glumes are spotted brown.
34-20	3-143	1-116	7-21	2-40	1-81	3-0	1-32	b	1-80	2-367	1-311	-753	
33-01	2-737	1-173	6-51	2-18	1-76	3-0	1-24	b	1-47	2-040	1-387	-745	
30-78	2-235	1-190	6-18	2-05	1-59	3-0	1-29	b-c	1-18	1-682	1-410	-752	Inner glumes show faint purple markings in furrows when un-ripe; colour gets intensified near ripening.
19-050	2-055	1-216	6-24	2-02	1-65	3-0	1-22	b-c	1-10	1-565	1-425	-761	Inner glumes show yellowish red colour with brown and purple markings in the furrows.
20-020	2-090	1-108	6-20	2-07	1-69	3-0	1-22	b-c	1-25	1-630	1-344	-803	Inner glumes are spotted brown.
56-000	1-370	1-087	5-26	1-73	1-44	3-0	1-20	c	-80	1-060	1-320	-773	Inner glumes show a shade of light orange.

(b) *Long.*

(i) *Large.*

66-500	3-220	1-20	7-48	2-51	1-83	2-08	1-37	b-d	1-86	2-620	1-492	-813	
44-020	2-960	1-18	7-42	2-52	1-86	2-04	1-35	b-d	1-73	2-47	1-425	-834	The degree of intensity of colour on the inner glumes varies in different places.
47-000	3-400	1-13	7-28	2-48	1-86	2-00	1-3	b-d	1-90	2-660	1-397	-782	Inner glumes show a light shade of orange and brown patches.
69-820	2-704	1-209	6-85	2-37	1-72	2-00	1-38	b-d	1-53	2-112	1-373	-781	

## APPEN

Type No.	Popular name	District	UNHULLED									
			Duration	Length m/m	Breadth m/m	Thickness m/m	Length of awns in inches	Shape	COLOUR OF			
									Outer glumes	Inner glumes	Awns	Appendix
38	Gauria . .	Barabanki .	L	8-86	2-63	2-04	..	B-D	r. p	l o	..	d. p
39	Ketki . .	Unao . .	E	9-12	2-17	1-85	5"-2"	C-D	d. p	e	d. p	d. p
40	Gajraj . .	Shahjahanpur .	L	8-80	2-30	1-77	..	C-D	w	c	..	..
41	Sogandharai .	Barabanki .	E	8-57	2-41	1-97	..	D	p	c	..	d. p
42	Anjana . .	Dehradun .	E	8-86	2-47	1-88	..	D	w	c	..	..
43	Sondhi . .	Etah . .	E	8-40	2-24	1-76	5"-2"	D	w	c	w	..
44	Katikwa . .	Mirzapur .	L	8-17	2-40	1-82	..	D	w	c	..	..
45	Barhni sarya .	Nepal border	V. L	7-89	2-89	1-83	1"-5"	C-D	w	c	bl. p	bl.
46	Nidhor . .	Bareilly .	E	7-61	2-04	1-60	..	C-D	w	c	..	r. p
47	Nidol . .	Nainital .	E	8-14	2-43	1-81	..	D	w	b	..	..
48	Champaoli . .	Etah . .	E	9-75	2-70	1-97	..	D-E	r. p.	d. o. r	..	bl.
49	Anjana . .	Bareilly .	E	8-28	2-46	1-83	..	D	l. p	c	..	d. p
50	Hanraj (Desi) .	Rampur state .	E	8-89	2-52	1-79	tiny bits to 1"	D	w	c	w	..
51	Lalkhu . .	Jhansi . .	E	8-98	2-43	1-90	..	D	w	o. r	..	..
52	Jhansi . .	Shahjahanpur .	L	9-30	2-56	1-90	tiny bits to 1"	D	w	l. o. r	w	..
53	Dadelaah pasand .	Unao . .	L	7-59	2-12	1-31	..	C-D	r. p	dl. bl. p	..	d. p
54	Morgi sarya . .	Nepal border	V L	7-74	2-11	1-74	..	C-D	bl. p	c	..	bl.
55	Gola maroo . .	Nepal border	E	8-56	2-40	1-86	t	D	w	c	w	..
56	Jalao . .	Hardoi . .	L	9-55	2-75	2-16	5"-1-5"	D-E	w	c	w	bl. p
57	Katika dhan . .	Jaunpur . .	L	9-05	2-83	2-14	t	D-E	w	c	w	..

## WHITE GRAIN

## (b) Long

## (i) Large

## (ii) Medium

DIX—*contd.*

GRAIN			HULLED GRAIN										REMARKS
WEIGHT OF		Specific gravity	Length m/m	Breadth m/m	Thickness m/m	PROPORTION BETWEEN		Shape	Volume of 100 grains c. c.	Weight of 100 grains in gram	Specific gravity	Proportion between weights of unhulled and hulled grain.	
One plant produce in gm.	100 grains in gram					Breadth and length	Thickness and breadth						

WHITE GRAIN—*contd.*(b) LONG—*contd.*(i) Large—*contd.*

55-100	2-800	1-100	6-80	2-82	1-79	2-90	1-30	b-d	1-56	2-170	1-388	·775	
37-770	2-037	1-233	6-09	2-05	1-61	2-90	1-26	c-d	1-10	1-550	1-409	·760	The colour of outer glumes fades away near ripening.
40-100	2-120	1-190	6-28	2-13	1-61	2-90	1-32	c-d	1-20	1-630	1-354	·768	Inner glumes are streaked light brown.
28-870	2-038	1-222	6-34	2-25	1-72	2-8	1-31	d	1-36	1-905	1-400	·722	The colour of outer glumes fades away near ripening.
20-00	2-411	1-109	6-42	2-28	1-71	2-8	1-33	d	1-41	1-930	1-362	·800	Inner glumes are streaked faint brown.
32-00	2-04	1-082	6-06	2-16	1-60	2-8	1-35	d	1-17	1-610	1-376	·789	
38-100	2-027	1-109	5-68	2-30	1-68	2-8	1-37	d	1-15	1-627	1-414	·802	Inner glumes show development of brown markings on some spikelets near ripening.
48-80	1-795	1-130	5-875	2-07	1-61	2-8	1-28	c-d	1-05	1-41	1-340	·785	
27-90	1-5	1-196	5-45	1-80	1-40	2-8	1-29	c-d	·84	1-204	1-430	·802	
40-035	2-832	1-150	6-16	2-21	1-58	2-8	1-40	d	1-23	1-760	1-425	·754	Inner glumes show orange brown colour in the furrows when young.
24-00	2-905	1-115	6-9	2-55	1-84	2-7	1-38	d-e	1-64	2-253	1-367	·752	Inner glumes show pale green colour with brown markings in the furrows when young.
42-00	2-420	1-225	6-19	2-26	1-66	2-7	1-36	d	1-35	1-860	1-374	·768	Inner glumes show crown streaks.
63-40	2-44	1-102	6-26	2-32	1-61	2-7	1-44	d	1-36	1-790	1-311	·793	
22-400	2-570	1-143	6-26	2-31	1-71	2-7	1-35	d	1-41	1-992	1-412	·775	
60-000	2-580	1-203	6-46	2-38	1-69	2-7	1-40	d	1-44	2-050	1-420	·794	
40-900	1-500	1-121	5-48	2-00	1-49	2-7	1-34	c-d	·80	1-272	1-421	·800	The outer surface of inner glumes is more black than the inner.
31-000	1-620	1-142	5-49	2-01	1-00	2-7	1-25	c-d	·93	1-270	1-360	·783	Inner glumes show faint purple dots.

## (ii) Medium.

44-330	2-353	1-327	6-22	2-37	1-66	2-6	1-42	d	1-38	1-955	1-411	·880	
57-200	3-255	1-133	6-71	2-63	1-97	2-5	1-33	d-o	1-88	2-54	1-340	·780	
51-900	2-970	1-128	6-54	2-63	1-93	2-5	1-36	d-o	1-64	2-30	1-400	·774	

## APPEN

Type No.	Popular name	District	UNHULLED									
			Duration	Length m/m	Breadth m/m	Thickness m/m	Length of awns in inches	Shape	COLOUR OF			
									Outer glumes	Inner glumes	Awns	Apiculus

## WHITE GRAIN

## (b) LONG

## (ii) Medium

58	Parewa . . .	..	L	8-27	2-57	1-92	..	D	p	d. o. r	..	same as inner gl.
59	Ajwaha . . .	Partabgarh . .	L	7-00	2-24	1-73	..	C-D	w	c	..	l. o
90	Kala shukhas . .	Banda . . .	L	7-56	2-28	1-71	t	C-D	p	r. o. b	r. b	d. b
61	Ramjai . . .	Allahabad . .	V. L	7-34	2-27	1-76	..	C-D	r p	o. r. b	..	o. r
62	Shamghata . . .	Partabgarh . .	L	6-73	2-14	1-53	..	C-D	bl. p	bl.	..	bl.
63	Lalsar . . .	Gonda . . .	E	8-16	2-59	1-89	1"-3"	D	p	d. o. r	d. p	d. p.
64	Lalkemri . . .	Fyzabad . . .	L	8-41	2-66	1-88	..	D-E	w	o. r.	..	..
65	Ajan dhan . . .	Banda . . .	E	8-11	2-49	1-78	..	D	w	c	..	..
66	Samhera . . .	Unao . . .	L	7-62	2-44	1-82	6"-2"	D	r. p.	d. r. b	h. r	p
67	Parjati . . .	Basti . . .	L	7-57	2-35	1-82	t	D	r. p	o. b	p	p

## (iii) Small

68	Khadey Khanjandi . .	Nepal border . .	L	9-39	3-02	1-93	..	E	w	l. o. r	..	..
69	Bajarhong . . .	Sultanpur . . .	L	8-56	2-33	2-05	..	D-E	w	bl.	..	p
70	Laldeha saryan . . .	Nepal border . .	V. L	8-83	2-94	2-45	..	D-E	w	d. o. r	.	..

DIX—*contd.*

GRAIN			HULLED GRAIN										REMARKS
WEIGHT OF		Specific gravity	Length m/m	Breadth m/m	Thickness m/m	PROPORTION BETWEEN		Shape	Volume of 100 grains c. c.	Weight of 100 grains in gram	Specific gravity	Proportion between weights of unhulled and hulled grain.	
One plant produce in gram.	100 grains in gram					Breadth and length	Thickness and breadth						
WHITE GRAIN— <i>contd.</i>													
(b) Long— <i>contd.</i>													
(ii) Medium— <i>contd.</i>													
62-300	2-460	1-177	5-95	2-39	1-81	2-5	1-82	d	1-41	1-900	1-344	-772	
39-900	1-780	1-093	5-34	2-11	1-54	2-5	1-87	c-d	1-06	1-405	1-328	-789	Inner glumes show brown streaks
38-800	1-665	1-131	5-47	2-13	1-57	2-5	1-35	c-d	1-01	1-400	1-388	-840	Inner glumes show irregular red orange brown colour.
62-306	1-720	1-136	5-41	2-15	1-58	2-5	1-36	c-d	-95	1-340	1-406	-779	Outer glumes do not show any colour when young.
60-400	1-250	1-154	4-87	2-02	1-40	2-5	1-44	c-d	-74	-985	1-325	-804	Inner glumes show more intense colour near the tip and on the outer surface. The colour of inner glumes is black when young; slightly fading away near ripening. Apiculus has the same colour as the inner glumes.
35-760	2-461	1-180	6-03	2-43	1-70	2-4	1-43	d	1-28	1-780	1-387	-723	Inner glumes show light orange colour when young. It becomes deep orange red near ripening. The spikelets near the base of the ear show faint colour and possess short awns.
55-150	2-375	1-201	6-08	2-49	1-70	2-4	1-46	d	1-41	1-970	1-394	-820	
57-140	2-415	1-192	5-78	2-35	1-57	2-4	1-49	d	1-23	1-717	1-388	-711	
75-150	1-920	1-212	5-44	2-24	1-63	2-4	1-37	d	1-04	1-500	1-438	-781	
41-800	2-025	1-182	5-49	2-22	1-60	2-4	1-38	d	1-06	1-500	1-411	-740	
(iii) Small.													
37-850	2-960	1-087	6-34	2-68	1-75	2-3	1-53	e	1-72	2-245	1-300	-758	
47-300	2-680	1-200	6-07	2-63	1-85	2-3	1-42	d-e	1-47	2-080	1-412	-707	Outer glumes show orange brown colour near ripening. The colour on the inner glumes is lighter in young spikelets and becomes more intense in the furrows than on the ridges. The colouration on the ear-head starts from top downwards. Apiculus shows black colour near ripening.
55-20	2-950	1-188	6-16	2-67	1-88	2-3	1-42	d-e	1-68	2-32	1-380	-786	

## APPEN

Type No.	Popular name	District	UNHULLED										
			Duration	Length m/m	Breadth m/m	Thickness m/m	Length of awns in inches	Shape	COLOUR OF				
									Outer glumes	Inner glumes	Awns	Apiculus	
WHITE GRAIN													
LONG													
Small													
71	Gauria . . .	Bareilly . . .	B	8-23	2-65	1-99	..	D-E	r. p	e	..	d. p	
72	Sonezard . . .	Sitapur . . .	L	8-54	3-10	2-16	-5"-1" in some.	E	r. p	d. l. o	r	p	
73	Shiamceera . . .	Hardoi . . .	B	8-15	2-77	1-07	..	D-E	w	e	..	..	
74	Suapankhi . . .	Sitapur . . .	L	8-45	2-71	1-99	..	D-E	w	dl. r. b	..	d. p	
75	Gunchchai . . .	Shahjahanpur . . .	L	7-30	2-48	1-85	..	D	w	e	..	..	
76	Ratho . . .	Allahabad . . .	L	8-60	3-04	2-07	..	E	w	l. o. b	..	..	
77	Bhalain . . .	Garhwal . . .	E	7-80	2-51	1-06	..	D-E	r. p	e	..	r. p	
78	Anandi . . .	Nainital . . .	M	8-52	2-97	1-08	..	D-E	w	e	..	..	
79	Bansphool . . .	Sultanpur . . .	L	8-13	2-12	1-76	..	C-D	o. b	e	..	bl. p	
80	Thapamasee . . .	Nepal border . . .	E	7-94	2-70	1-89	..	D-E	w	e	..	d. p	
81	Aklwa . . .	Basti . . .	L	7-50	2-57	1-87	..	D-B	w	o. r	..	..	
82	Ramkalewa . . .	Mirzapur . . .	L	6-12	2-07	6-52	..	C-F	w	e	..	..	
(c) SHORT													
(i) Large													
83	Sudarshana . . .	Cawnpore . . .	L	7-95	2-89	2-15	-5"-2"	E	r. p	dl. e	r. p	p	
84	Jardhan . . .	Cawnpore . . .	E	7-48	2-77	1-08	..	E	w	e	..	p	
85	Pahla toli . . .	Nepal border . . .	M	7-22	2-76	1-97	..	D	w	e	..	d. p	
86	Ramkajra . . .	Gonda . . .	M	7-26	2-73	1-81	t	D-F	w	e	p	d. p	
87	Safeda . . .	Hardoi . . .	M	7-45	2-68	1-87	..	D-F	w	e	..	..	
88	Chakia . . .	Fyzabad . . .	L	8-19	3-12	2-18	t	E	w	e	w	..	
89	Musra . . .	Etah . . .	E	7-80	3-01	2-12	..	D-F	l. p	e	..	bl.	
90	Kalonji . . .	Jhansi . . .	M	7-43	2-79	1-97	..	D	r. p	e	..	d. p	
91	Shatoo marsee . . .	Nepal border . . .	M	7-38	2-78	1-94	..	D-F	w	e	..	..	
92	Sondhi . . .	Badaun . . .	L	7-14	2-80	1-84	..	D-F	w	e	..	l. o	

DIX—*contd.*

GRAIN			HULLED GRAIN										REMARKS
WEIGHT OF		Specific gravity	Length m/in	Breadth m/in	Thickness m/in	PROPORTION BETWEEN		Shape	Volume of 100 grains c. c.	Weight of 100 grains in gram.	Specific gravity	Proportion between weights of unhulled and hulled grain.	
One plant produce in gram.	100 grains in gram.					Breadth and length	Thickness and breadth						

WHITE GRAIN—*contd.*

LONG.

Small.

43-530	2-800	1-222	5-71	2-48	1-82	2-3	1-36	d-e	1-51	2-145	1-415	-750	The colour of outer glumes fades away near ripening.
56-540	3-100	1-158	6-24	2-81	1-08	2-2	1-41	e	1-82	2-54	1-303	-796	
43-73	2-743	1-206	5-75	2-00	1-75	2-2	1-48	d-e	1-47	2-025	1-374	-738	
48-600	2-700	1-142	5-84	2-61	1-82	2-2	1-43	e	1-47	2-080	1-412	-770	The outer glumes are white and long; reaching the tip of the spikelets.
55-700	1-96	1-150	5-30	2-32	1-63	2-2	1-42	d	1-07	1-52	1-416	-724	
60-550	2-94	1-170	6-00	2-86	1-90	2-1	1-50	e	1-72	2-390	1-387	-812	
18-800	2-315	1-140	5-56	2-58	1-74	2-1	1-48	d-e	1-33	1-795	1-349	-775	Inner glumes are dotted brown.
25-550	2-710	1-101	5-61	2-63	1-79	2-1	1-47	d-e	1-34	1-870	1-390	-690	
46-600	1-750	1-180	5-88	2-075	1-57	2-1	1-32	e-e	-95	1-350	1-416	-770	
28-460	2-425	1-180	5-40	2-53	1-72	2-1	1-47	d-e	1-27	1-790	1-403	-738	
38-400	2-23	1-179	5-25	2-40	1-70	2-1	1-41	d-e	1-24	1-760	1-415	-789	
40-600	1-185	1-136	4-24	1-98	1-49	2-1	1-32	e-f	-06	-050	1-482	-801	

(e) SHORT.

(i) Large.

43-300	2-075	1-080	5-07	2-78	2-02	2	1-37	e	1-56	2-085	1-329	-779	Inner glumes are streaked brown.
52-400	2-41	1-106	5-45	2-63	1-85	2	1-42	e	1-32	1-857	1-404	-770	
41-870	2-172	1-212	5-26	2-61	1-79	2	1-45	d	1-19	1-71	1-437	-787	
11-05	1-89	1-179	5-01	2-43	1-66	2	1-46	d-f	1-09	1-48	1-354	-783	The variety is generally sown broadcast. Some of the outer glumes show pink colour. Apiculus colour fades away near ripening.
11-22	2-06	1-181	5-20	2-48	1-70	2	1-45	d-f	1-20	1-610	1-338	-781	
52-300	3-000	1-148	5-69	2-98	1-60	1-9	1-49	e	1-71	2-42	1-441	-806	
43-900	2-635	1-190	5-45	2-81	1-94	1-0	1-44	d-f	1-53	2-072	1-354	-771	The variety is generally sown broadcast. Inner glumes dotted brown.
28-160	2-245	1-197	5-25	2-64	1-70	1-9	1-47	d	1-24	1-785	1-439	-795	
21-000	2-065	1-098	5-17	2-64	1-77	1-9	1-49	d-f	1-17	1-634	1-391	-791	
40-630	2-065	1-175	5-14	2-61	1-63	1-9	1-60	d-f	1-12	1-620	1-445	-773	Some inner glumes shown brown dots.

## APPEN

Type No.	Popular name	District	UNHULLED									
			Duration	Length m/in	Breadth m/in	Thickness m/in	Length of awns in inches	Shape	COLOUR OF			
									Outer glumes	Inner glumes	Awns	Apiculus
WHITE GRAIN												
(c) SHORT												
(i) Large												
93	Mutimuri agahnt . .	Jaunpur . .	L	7-35	2-82	1-99	tiny bits to 1"	D-F	r. p	dl. o	r. p	d. p.
94	Kaladhan . .	.....	L	7-68	2-95	2-13	..	E	w	dl. e	..	p
95	Samhera . .	Unao . .	L	6-85	2-68	1-93	1"-2"	D-F	r. p	l. r. b	r. b	p
96	Manki . .	Banda . .	E	5-52	2-09	1-44	..	C-D	w	d. o. r	..	..
97	Dhan kammun . .	Nainital . .	L	6-30	2-40	1-81	..	D-F	l. p	l. o. b	..	bl.
98	Kanakziri pila . .	Jaunpur . .	V. L	6-04	2-21	1-63	..	D-F	w	o. r. b	..	p
99	Kanakziri . .	Nepal border	V. L	5-95	2-23	1-67	..	F	bl. p	bl. p	..	bl. p
(ii) Medium												
100	Bhenslot . .	Azamgarh . .	L	7-79	3-24	2-44	..	E	w	l. o	..	p
101	Rahmanwan . .	Kheri . .	L	7-62	2-73	1-97	..	E-F	l. r	dl. e	..	r. b
102	Mutimuri . .	Allahabad . .	M	6-70	2-90	1-94	t	D-F	l. r	e	p	p
103	Paoni . .	Jhansi . .	M	6-47	2-84	1-97	..	D	w	dl. o. r	..	..
(iii) Small												
104	Gola . .	Nepal border . .	L	6-12	2-63	1-73	..	D-F	w	e	..	..
105	Dhani . .	Mainpuri . .	L	6-50	2-71	1-99	5"-2"	D-F	r. p	dl. e	r. p	r. p
106	Garri . .	Nainital . .	M	5-39	2-47	1-92	..	F	r. p	bl.	..	bl. p
107	Mahoki . .	Azamgarh . .	L	6-63	3-05	1-99	..	F	w	e	..	..
108	Goin gode marsee . .	Nepal border . .	M	5-61	2-75	2-01	..	F	w	dl. o. b	..	..
109	Nania . .	Lucknow . .	M	6-27	3-15	2-02	..	F	w	e	..	..
110	Ramjai . .	Allahabad . .	L	5-50	2-64	1-90	..	F	w	e	..	r. p

DIX--*contd.*

GRAIN			HULLED GRAIN										REMARKS
WEIGHT OF		Specific gravity	Length m/m	Breadth m/m	Thickness m/m	PROPORTION BETWEEN		Shape	Volume of 100 grains c. c.	Weight of 100 grains in gram	Specific gravity	Proportion between weights of unhulled and hulled grain.	
One plant produce in gm.	100 grains in gram					Breadth and length	Thickness and breadth						

WHITE GRAIN—*concl.*(c) SHORT—*contd.*(i) Large—*contd.*

54-800	2-345	1-167	5-19	2-66	1-79	1-9	1-48	d-f	1-26	1-705	1-344	-727	Some inner glumes show dull appearance.
30-100	2-640	1-171	5-36	2-77	1-65	1-9	1-42	d	1-51	2-07	1-368	-784	Outer glumes show purple colour near ripening. Inner glumes show purple colour in the furrows, which fades away near ripening.
52-970	1-850	1-198	4-83	2-51	1-70	1-9	1-47	d-f	-99	1-98	1-390	-746	The colour of inner glumes fades away near ripening.
29-320	1-309	1-200	4-07	2-07	1-38	1-9	1-50	e-d	-68	-944	1-380	-721	
28-200	1-572	1-151	4-48	2-20	1-63	1-9	1-38	d-f	-87	1-215	1-391	-772	
50-250	1-260	1-142	4-08	2-06	1-51	1-9	1-36	d-f	-81	1-120	1-377	-888	Inner glumes show brown dots when young.
19-500	1-350	1-103	4-16	2-12	1-54	1-0	1-37	f	-79	1-03	1-362	-800	

## (ii) Medium.

57-72	3-215	1-173	5-43	3-09	2-24	1-8	1-37	f	1-88	2-54	1-348	-790	
53-55	2-07	1-141	4-72	2-66	1-80	1-7	1-47	e-f	1-13	1-570	1-355	-758	
14-54	2-235	1-159	4-63	2-65	1-74	1-7	1-52	d-f	1-26	1-700	1-346	-760	The variety is generally sown broadcast.
5-92	1-92	1-140	4-47	2-63	1-78	1-7	1-47	d	1-11	1-520	1-366	-701	The variety is generally sown broadcast. Inner glumes show pale yellow mottlings in furrows.

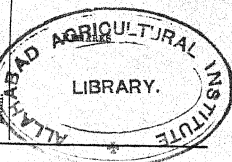
## (iii) Small.

31-900	1-585	1-222	4-12	2-43	1-55	1-6	1-60	d-f	-88	1-240	1-401	-782	Some inner glumes show brown dots.
56-300	1-85	1-167	4-31	2-61	1-86	1-6	1-40	d-f	1-06	1-500	1-411	-810	
34-800	1-320	1-112	3-71	2-24	1-70	1-6	1-31	f	-77	1-040	1-350	-781	Inner glumes show blackish purple mottlings which get intensified near ripening.
30-600	1-969	1-080	4-42	2-84	1-76	1-5	1-61	f	1-12	1-512	1-344	-767	
35-900	1-832	1-105	4-11	2-78	1-97	1-4	1-41	f	1-17	1-577	1-345	-860	
10-20	2-01	1-160	4-14	2-91	1-83	1-4	1-50	f	1-13	1-400	1-315	-741	The variety is generally sown broadcast.
52-000	1-195	1-163	3-66	2-53	1-72	1-4	1-47	f	-81	1-125	1-392	-800	Outer glumes show light red colour near ripening. Inner glumes show a little brownish shade.

Type No.	Popular name.	District	UNHULLED									
			Duration	Length m/m	Breadth m/m	Thickness m/m	Length of awns in inches	Shape	COLOUR OF			
									Outer glumes	Inner glumes	AWBS	Aplurhus
111	Dodo . . .	Garhwal . .	E	10-26	2-39	1-05	..	B	w	h, y	..	..
112	Bansmati . .	Saharanpur .	M	8-71	2-02	1-64	..	A-C	w	e	..	..
II. RED GRAIN												
(a) SLENDER												
(iii) Small												
113	Kapoor sari . .	Mirzapur . .	M	8-18	2-32	1-42	..	D	w	dl. o. b	..	l. p.
114	Chambha (swaed) .	Saharanpur .	E	9-08	2-70	2-07	tiny bits to 1-5"	B-D	w	e	w	..
115	Gutechhai . .	Basti . .	V. L	8-99	2-47	1-75	..	B-D	w	l. o. r	..	..
116	Agahni safed . .	Ballia . .	L	9-32	2-61	2-04	..	B-D	w	dl. e	..	..
(i) Large												
(ii) Midway												
117	Sankhercha . .	Nainital . .	E	8-01	2-42	1-73	..	D	w	d. o. r	..	..
118	Nahan or mahachha .	Etah . .	E	8-57	2-57	1-05	..	D	w	e	..	..
119	Lohni . .	Jaunpur . .	I.	8-5	2-45	1-77	..	D	w	l. o. r	..	..
120	Kato tali . .	Nepal border .	E	8-63	2-64	1-87	..	D-E	w	bl.	..	..
(iii) Small												
121	Ram kajra . .	Allahabad . .	M	7-36	2-52	1-79	..	D	d. r. p	dl. b	..	bl. b
122	Dodha . .	Nainital . .	E	8-61	2-84	2-00	..	D-E	d. p	e	..	..
123	Bansmati . .	Allahabad . .	M	7-14	2-54	1-80	..	D	w	o. r	..	..
124	Ram kajra . .	Gonda . .	E	7-83	2-94	2-05	..	E	d. p	e	..	bl.
125	Anandi sarya . .	Nepal border .	V. L	8-31	2-60	1-90	..	E	w	d. o. r	..	..
126	Anjana . .	Dehradun . .	E	8-31	2-81	1-94	..	D	w	e	..	..

DIX—*contd.*

GRAIN			HULLED GRAIN									
WEIGHT OF		Specific gravity	Length m/m	Breadth m/m	Thickness m/m	PROPORTION BETWEEN		Shape	Volume of 100 grains c. c.	Weight of 100 grains in gram.	Specific gravity	Proportion between weights of unhulled and hulled grain
One plant produce in gm.	100 grains in gram.					Breadth and length	Thickness and breadth					
30-30	2-857	1-196	7-21	2-19	1-78	3-3	1-23	b	1-57	2-202	1-304	-770
30-00	1-505	1-160	7-21	2-40	1-81	3-2	1-82	a-c	.94	1-275	1-352	-799
(a) SLENDER.												
(iii) Small.												
30-30	2-857	1-196	7-21	2-19	1-78	3-3	1-23	b	1-57	2-202	1-304	-770
30-00	1-505	1-160	7-21	2-40	1-81	3-2	1-82	a-c	.94	1-275	1-352	-799
(b) LONG.												
(i) Large.												
10-10	1-720	1-144	5-85	2-01	1-49	2-9	1-34	d	.97	1-310	1-346	-761
36-80	3-285	1-188	7-11	2-51	1-89	2-8	1-82	b-d	1-84	2-592	1-407	-789
27-10	2-270	1-100	6-5	2-28	1-57	2-8	1-45	b-d	1-24	1-705	1-366	-751
58-70	2-785	1-164	6-47	2-38	1-81	2-7	1-81	b-d	1-57	2-110	1-341	-771
(ii) Medium.												
30-04	2-155	1-187	5-85	2-22	1-55	2-6	1-43	d	1-13	1-637	1-355	-713
65-30	2-520	1-104	6-23	2-42	1-75	2-5	1-38	d	1-44	2-020	1-397	-801
57-00	2-305	1-103	6-0	2-37	1-59	2-5	1-49	d	1-32	1-785	1-350	-773
17-40	2-785	1-080	6-23	2-51	1-75	2-4	1-43	d-c	1-68	2-115	1-258	-759
(iii) Small.												
7-45	1-78	1-117	5-13	2-21	1-65	2-3	1-33	d	1-05	1-40	1-330	-786
17-30	2-002	1-181	6-14	2-09	1-83	2-2	1-47	d-c	1-55	2-197	1-415	-757
7-67	1-86	1-111	5-28	2-35	1-58	2-2	1-48	d	1-04	1-38	1-323	-741
44-70	3-042	1-102	5-86	2-72	1-84	2-1	1-47	e	1-61	2-235	1-400	-741
35-40	2-20	1-041	5-67	2-46	1-70	2-2	1-44	e	1-23	1-67	1-354	-759
30-80	2-293	1-162	5-50	2-60	1-80	2-1	1-44	d	1-58	1-80	1-303	-785



UNHULLED												
Type No.	Popular name	District	Duration	Length m/m	Breadth m/m	Thickness m/m	Length of awns in inches	Shape	COLOUR OF			
									Outer glumes	Inner glumes	Awms	Apiculus
II. RED GRAIN												
(b) Long												
(iii) Small												
127	Sanhera . . .	Unao . . .	L	7.45	2.75	1.06	5"-2"	D	w	dl. c	c	bl. p
128	Deola . . .	Sultanpur . . .	M	8.20	3.06	1.03	..	D-E	w	e	..	..
(c) SHORT												
(i) Large												
129	Kanakstir . . .	Partabgarh . . .	V. L	6.77	2.25	1.05	..	D	bl. p	bl.	..	same as inner glume
130	Sourha . . .	Bareilly . . .	M	7.68	2.01	1.07	tiny bits to 2-5"	D-E	w	d. l. b	b	..
131	Sathi (awnless black).	Ghaziipur . . .	E	6.9	2.85	1.83	..	D-E	w	bl.	..	r. p
(ii) Medium												
132	Sathi (black awned).	Saharanpur . . .	E	7.12	3.19	1.08	tiny bits to 1-5"	E	w	bl.	w	p
133	Sathi (white awned).	Saharanpur . . .	E	7.11	3.05	1.02	tiny bits to 1-5"	D-E	w	w	w	..
134	Ramkajra . . .	Darabanki . . .	E	6.72	2.77	1.07	..	D-E	d. p	e	..	bl.
135	Dilbakhaha . . .	Allahabad . . .	L	5.71	2.39	1.02	..	F	w	dl. c	..	..

DIX—*conold*.

GRAIN			HULLED GRAIN										REMARKS
WEIGHT OF		Specific gravity	Length m/m	Breadth m/m	Thickness m/m	PROPORTION BETWEEN		Shape	Volume of 100 grains c. c.	Weight of 100 grains in gram	Specific gravity	Proportion between weights of un-hulled and hulled grain.	
One plant produce in gram.	100 grains in gram					Breadth and length	Thickness and breadth						

RED GRAIN—*contd.*(b) Long—*contd.*(iii) Small—*contd.*

81-13	2-105	1-197	5-21	2-43	1-30	2-1	1-34	d	1-23	1-70	1-325	-807	
10-04	2-05	1-171	5-73	2-77	1-75	2-1	1-53	d-e	1-48	2-02	1-360	-762	The variety is generally sown broadcast. Inner glumes show dark brown dots in furrows.

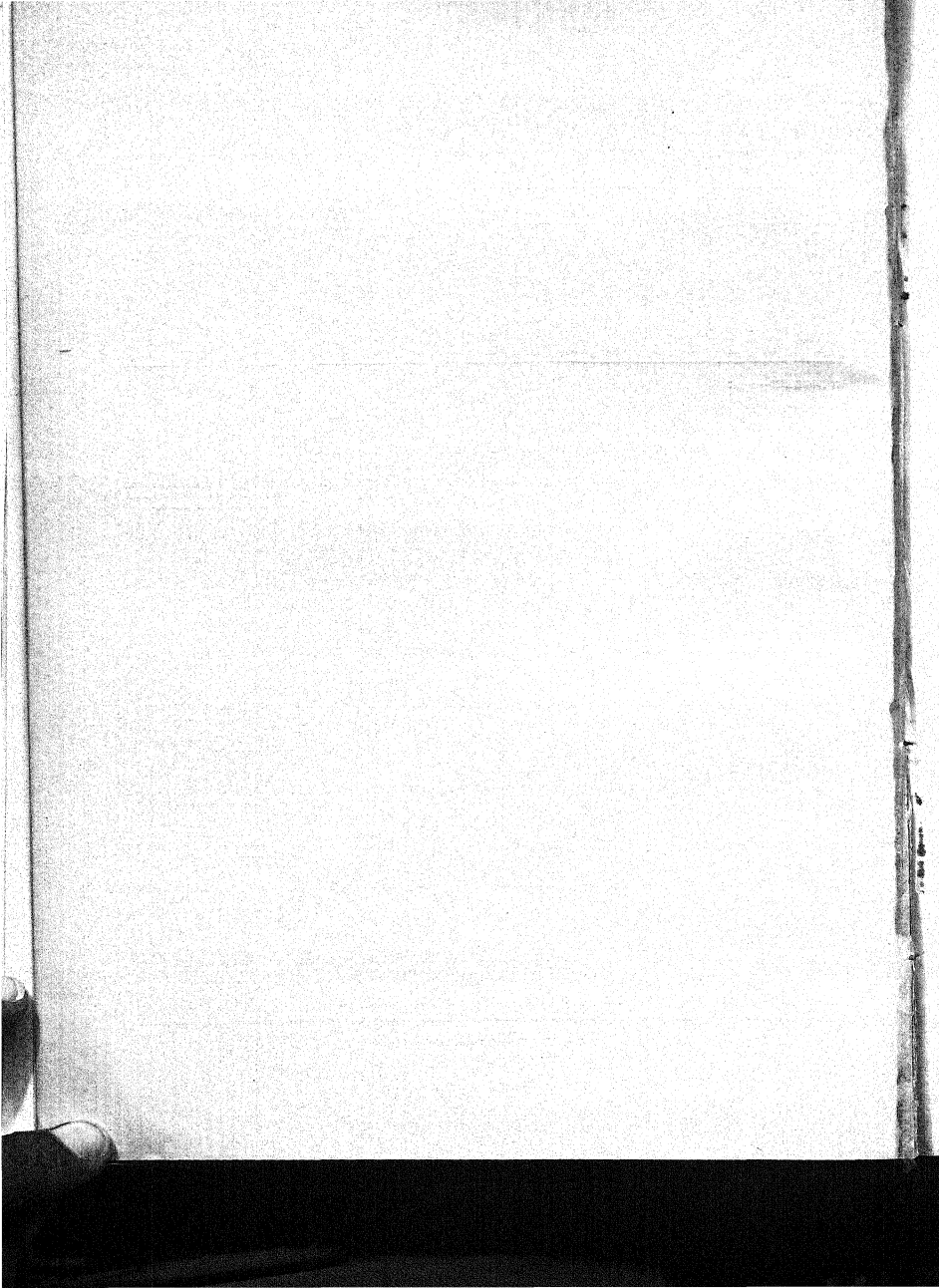
## (c) Short.

## (i) Large.

45-85	1-57	1-100	4-52	2-13	1-52	2	1-43	d	-34	1-15	1-304	-732	
11-01	2-24	1-146	5-27	2-62	1-75	2	1-49	d-e	1-30	1-760	1-350	-735	The variety is generally sown broadcast.
0-4	2-05	1-162	5-22	2-63	1-65	1-0	1-50	d-e	1-22	1-615	1-315	-737	The variety is the famous broadcast type of the United Provinces. Inner glumes are streaked black when young; black when ripe.

## (ii) Medium.

0-3	2-00	1-122	5-29	2-92	1-84	1-8	1-53	e	1-75	2-24	1-277	-772	The variety is the famous broadcast type of the United Provinces. Awns are white when young; turning black near ripening. Apiculus is purple when young becomes black near ripening.
13-06	2-36	1-110	5-23	2-85	1-70	1-8	1-50	d-e	1-40	1-35	1-360	-826	The variety is the famous broadcast type of the United Provinces. Inner glumes are streaked dirty brown in furrows.
38-74	2-455	1-212	4-03	2-53	1-74	1-8	1-45	d-e	1-23	1-723	1-381	-703	Inner glumes show brownish red markings when young. These fade away near ripening.
30-40	1-13	1-101	3-74	2-23	1-41	1-6	1-53	f	-63	-370	1-370	-770	



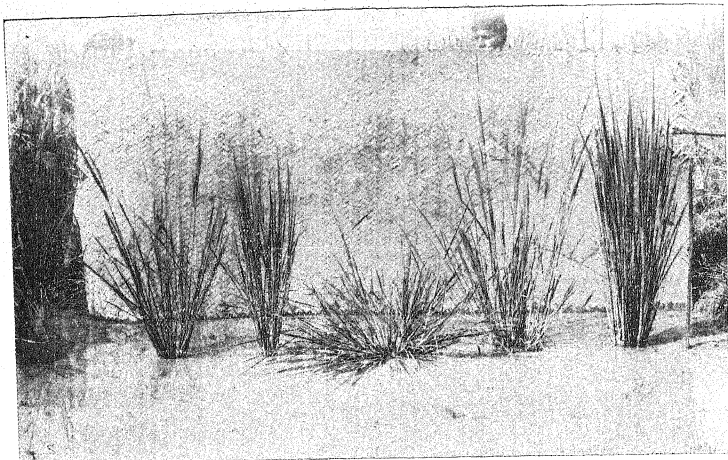
## PREFACE.

General breeding work and a study of the inheritance of certain characters of the rice plant were started at Coimbatore by Parnell in the year 1914. He published his early work on some of the simple cases in Memoirs of the Department of Agriculture, India, Botanical Series, Volume IX, No. 2, and Volume XI, No. 8. He had other more complicated cases under investigation and a great deal of valuable material has accumulated which Parnell intended to write up. In 1924, however, he left India suddenly to take up the post of Cotton Breeder under the Empire Cotton Growers' Corporation in South Africa. He took the records away with him but was unable to deal with them, and they were returned to Coimbatore in 1926. In the same year the writer went to England for further studies, and the rapid expansion of the Paddy Section made it impossible for R. O. Iliffe, who had succeeded Parnell, to collate the records and prepare them for publication. As other work of the section was waiting for publication and as other writers were already dealing with some of the subjects, the Government of Madras agreed to put the writer on special duty for six months on his return from England to deal with these records, and the work is now in progress. They will form separate issues of these Memoirs.

The present paper records work done after the departure of Parnell when the writer was in charge of the Paddy Section before he left for England. The work was nearing completion by that time and the writer is indebted to Iliffe for allowing him to include in this publication some of the results obtained in the 1926-27 season, and also for suggestions offered.

Acknowledgments are also due, in no small measure, to the senior assistants, S. Jobitharaj and S. Dharmalinga Mudaliar, to whom much of the field work is due.

K. RAMIAH.



1. Segregation for habit in a natural cross with wild rice.



2. Two pure lines growing in adjacent beds, one with the *compact* habit, and the other with the *spreading* habit.

NOTE.

In Plates VII and VIII the colours are not quite true to the originals: in plate VII both seedlings are lighter in colour than the originals and the yellow seedlings should show a more definite green tinge. In plate VIII the ripe grain with the purple glume should be much darker. In Plate IX the lower figure does not show the chimera clearly; in the original the purple glumes were much darker.



# THE INHERITANCE OF CHARACTERS IN RICE, PART III.

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## I. Inheritance of Habit in Rice.

### INTRODUCTION.

The characters in which the rice varieties differ from each other are extremely varied. On the one hand, we have morphological characters affecting the colour, size, shape, etc., of various parts of the plant; on the other hand, are such physiological characters as determine water requirement, length of duration, vigour, etc. The variations shown in some of these characters have been made use of by several authors in attempting the classification of rices. An examination of different varieties of rice reveals an interesting range of variation with regard to habit. By the term "habit" is here meant the manner of arrangement in nature, of the tillers, and the magnitude of their inclination to the vertical plane. At one extreme we have the real wild rices where the shoots actually creep along the surface in the early stages, a typical procumbent habit, and at the other extreme we have some cultivated forms where the tillers rise absolutely vertically and remain so until the finish of the reproductive phase.

Attempts were made as early as 1916-17, when Parnell was the Government Economic Botanist at Coimbatore, to study the inheritance of the procumbent habit associated with the wild rices, by isolating and growing some of the natural crosses observed in the plot of the semi-wild rices at the Paddy Breeding Station, Coimbatore. Plate I, fig. 1 shows the different types that were noticed in the progenies, the central one being the procumbent type. The magnitude of the angle of deviation from the vertical of the tillers of each plant was measured by a specially made protractor. Though there were indications in the ratios obtained that the procumbent habit was a Mendelian dominant, there appeared to be no clue to the number of factors involved. The work was, however, unfortunately not pursued.

So far as the cultivated rices are concerned two distinct habits of growth can be made out. In one the stems or tillers are closely grouped together and maintain an almost vertical—the *compact* habit. In the other the tillers spread out and are inclined in varying degree to the vertical, exhibiting the *spreading* habit. Plate I, fig. 2 represents two pure lines with the *spreading* and *compact* habits respectively

growing in adjacent plots. Beale<sup>1</sup> has recognized the existence of these two types in his scheme of classification of Burma rices. The subject matter of this note deals with the investigations on the inheritance of these two habits in the cultivated rices.

#### MATERIAL AND PROCEDURE OF INVESTIGATION.

Although rice is essentially a self-fertilised crop, natural cross pollination has been noted to occur by various workers, and in Coimbatore the percentage of natural crossing has been estimated to vary from 0.1 to 3.0.<sup>2</sup> But later work has shown that this may go up to even 6 to 7 per cent. under very favourable circumstances. From the very beginning of the rice breeding work in Coimbatore, it has been the practice to examine carefully the collections of pure lines and to isolate the aberrant types occurring in them for further study. It is from such study that most of the published results<sup>2</sup> & <sup>3</sup> about inheritance of simple characters were obtained. Wherever it was found necessary, the results obtained from the study of the natural crosses were later confirmed by making definite crosses with known parents. The same method was adopted for the study of the habit inheritance.

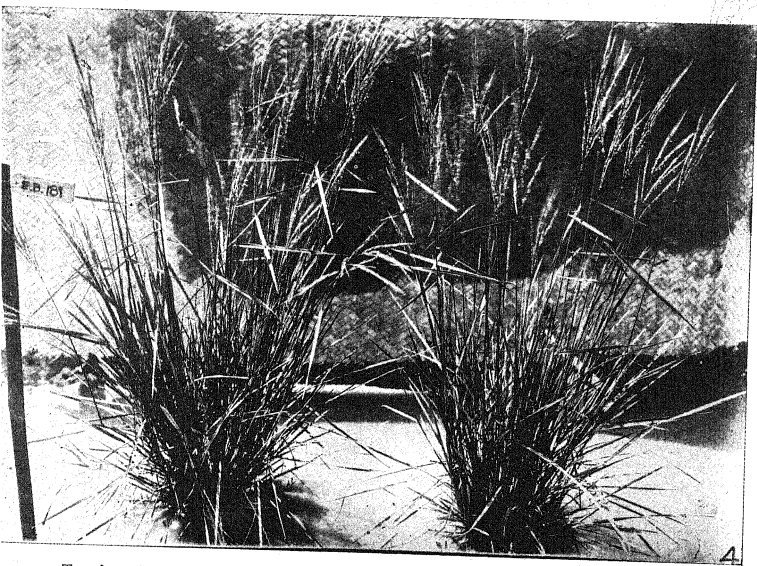
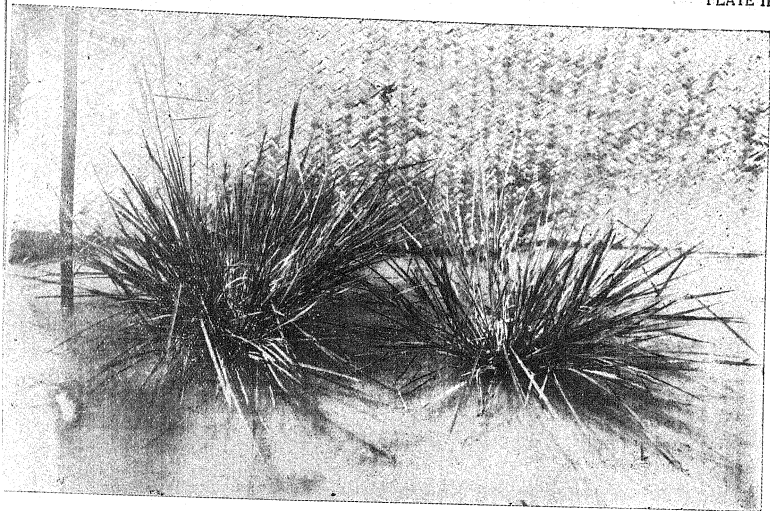
It must be stated that the angle which the tillers make with the vertical does not always remain constant. Even in varieties with partially procumbent habit, there is a tendency for the shoots to bend at the second and the third nodes above ground or water level and become vertical above that region, just at the commencement of the flowering stage of the plant. When the seeds are all set and getting ripe, the tillers again bend over and assume a semi-procumbent habit. Plate II, and Plate III, fig. 1 are photographs of two plants of a semi-wild rice taken at three stages of development, tillering stage, flowering stage, and ripening stage. With such variations occurring in all the rices, though not to the same degree, it was considered desirable to confine the observations on habit to the flowering stage only and all the results mentioned in this note refer only to such observations.

In the year 1923-24, the  $F_2$  of a natural cross isolated from the variety T. 298 was grown for the study of inheritance of the type of panicle, lax and dense. Since the numbers were not large enough to throw definite light on the problem, it was decided to grow the whole progeny of the 81 plants as  $F_3$  in 1924-25. Though these were mainly intended for a study of variation in panicle type, it was incidentally observed in the initial stages of the crop that there was considerable variation in the habit of the plants in the different families. An attempt was made to classify the plants individually as *spreading* and *compact* in each family. Plate III, fig. 2 depicts the range of variation in habit obtained in the group. Though in the be-

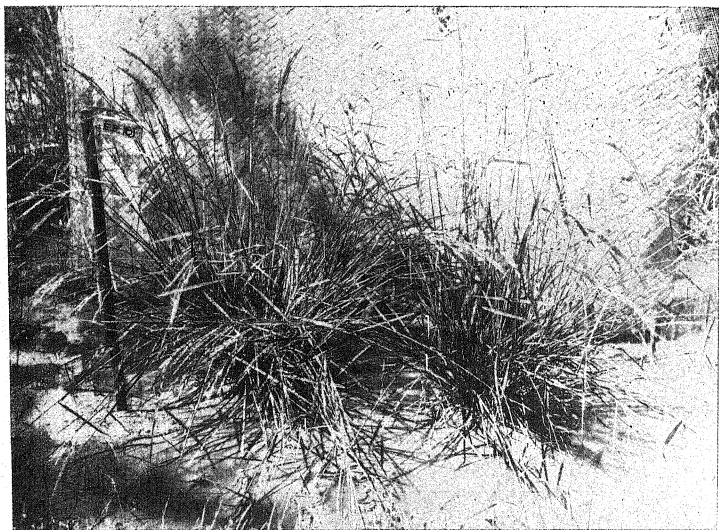
<sup>1</sup> Beale, R. A. A scheme of classification of the varieties of rice found in Burma. *Pusa Agricultural Research Institute Bulletin* No. 167.

<sup>2</sup> Parnell, F. R., Rangaswami Ayyangar, G. N., and Ramiah, K. The Inheritance of Characters in Rice. *Mem. Dept. Agri. India, Botanical Series*, Vol. IX, No. 2.

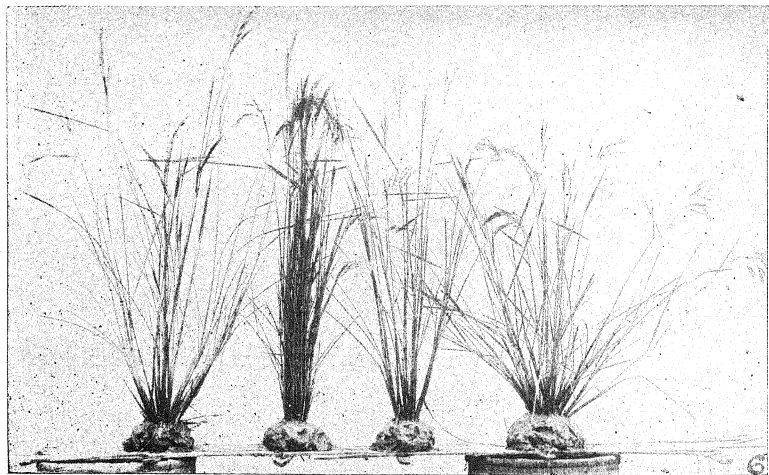
<sup>3</sup> & Parnell, F. R., Rangaswami Ayyangar, G. N. and Ramiah, K. "The Inheritance of Characters in Rice," *Mem. Dept. Agri. India, Botanical Series*, Volume IX, No. 2, Vol. XI, No. 8.



Two plants of a semi-wild rice photographed at different stages of development. Note the change in habit.



Two plants of a semi-wild rice photographed at different stages of development. Note the change in habit.



2. Segregation for compact and spreading habit.

ginning attempts were made to classify different groups according to their degree of spreading, the procedure was abandoned eventually, owing to the difficulties of defining the class limits. Only two were maintained, one the typical *compact* group, and the other composing all the different grades of the *spreading* habit.

The total number of families examined for the character were 81 of which—

- 19 bred pure for the *spreading* habit,
- 21 bred pure for the *compact* habit, and
- 41 segregated giving the two types.

The 41 segregating families gave a total of—

—	<i>Spreading</i>	<i>Compact</i>	<i>Deviation</i>	$\frac{\text{Deviation}}{\text{S. E.}^*}$
	5,524	1,680		
Cal. 3 : 1 . . .	5,403	1,801	121	3.3

The ratios definitely indicate that the *spreading* habit is a simple dominant over the *compact* habit. In the same year the  $F_2$ s of two other families—natural crosses again—isolated from a pure line with the *compact* habit were found to segregate for the habit and the ratios obtained are given below.

Family No.	<i>Spreading</i>	<i>Compact</i>		
5639	575	210	Dev.	$\frac{\text{Dev.}}{\text{S. E.}}$
5640	535	239		
TOTAL . . .	1,110	449		
Cal. 3 : 1 . . .	1,170	389		
			60	3.5

To get further confirmatory results, one of the  $F_3$  families of the first 41 segregating lots, No. 5622, which gave 154 *spreading* to 54 *compact* was selected, and the whole progeny was grown in 1925-26 season, planting about 110 seedling plants from every  $F_3$  progenitor plant. Only 204  $F_4$  families were actually raised, and it was found that of these—

- 47 bred pure for the *spreading* habit,
- 49 bred pure for the *compact* habit, and
- 108 segregated for the two types.

\* The standard error was calculated from the formula  $\text{S. E.} = \sqrt{\frac{pq}{n}}$ , where p and q are the expected ratios, and n the number of observations.

The ratios obtained for the 108 segregating families were—

—	<i>Spreading</i>	<i>Compact</i>	<i>Deviation</i>	$\frac{\text{Deviation}}{\text{S. E.}}$
	9,277	3,170		
<i>Cal. 3 : 1</i>	9,335	3,112	58	1.2

While the  $F_2$ s and the  $F_3$ s did not give a very good 3 : 1 ratio, the ratios of the  $F_4$ s are considerably closer.

With the knowledge that the *spreading* and *compact* habits form a simple pair of Mendelian allelomorphs, several of the pure lines with the typical *compact* habit had been gone over carefully in the previous season for the occurrence of natural hybrids with the *spreading* habit. The examination had resulted in the obtaining of half a dozen aberrant types which, when grown as  $F_2$ s in 1925-26, gave ratios given below—

Family No.	Isolated from pure line	Spreading	Compact	
6251 . . . . .	T. 2447	194	61	
6252 . . . . .	E. B. 143	169	40	
6256 . . . . .	„ 320	218	84	
6257 . . . . .	„ 320	204	102	
6258 . . . . .	„ 320	199	52	
6260 . . . . .	„ 321	194	60	
TOTALS .		1,178	399	$\frac{\text{Deviation}}{\text{S. E.}}$
<i>Cal. 3 : 1</i> . . . . .	..	1,183	394	5 0.03

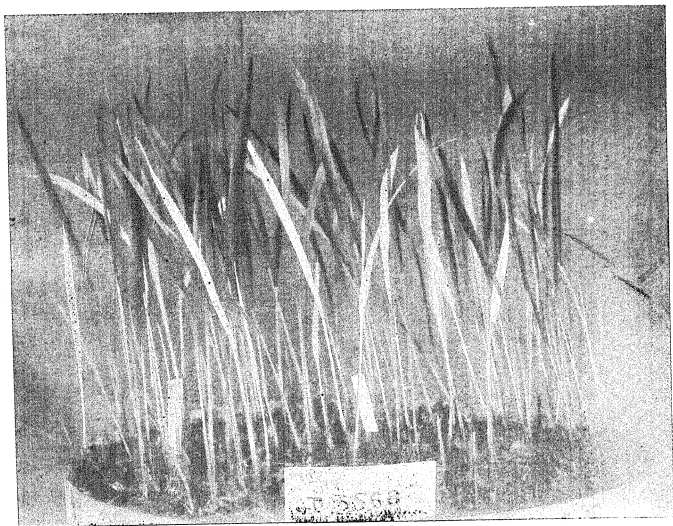
The behaviour of all the above families selected from four different varieties gives additional confirmatory evidence as to the simple recessive nature of the *compact* habit.

#### CONFIRMATORY EVIDENCE.

In addition to the information obtained from the study of the natural crosses a definite cross was made between two types—the probable parents of the original aberrant type in 1924-25. Plate IV, fig. 1 gives the two parents with the  $F_1$  in the middle. The  $F_1$  can be seen to have the dominant *spreading* habit like the



1. Two parents with the  $F_1$  in middle. Note the dominance of the *spreading* habit in the  $F_1$ .



2. A family segregating for the lethal albinos.



*spreading* parent. Three  $F_2$  families, all selfed material, were raised in 1926-27 and the table below gives the ratios obtained.

Family No.	Spreading	Compact		
6549 . . . . .	485	163		
6550 . . . . .	441	169		
6551 . . . . .	445	143		
TOTAL . . . . .	1,371	475	Dev.	Dev.
Cal 3 : 1 . . . . .	1,385	461	14	S. E. 0.75

An attempt was made to reduce the characters to actual measurements. A specially devised protractor was used to measure the angle of deviation from the vertical which the tillers make in each plant. A line of each of the parents had been planted both at the  $F_1$  and  $F_2$  stages. In one of the  $F_2$  families, No. 6551, the angles were measured for the plants with the two habits of growth separately. The details of the measurements are given below—

	Range of variation of the angle measured in degrees	Mean angle of deviation	Co-efficient of variability
T. 10. Compact Parent . . . . .	4 to 11	7.08 $\pm$ .39	25.4
T. 27. Spreading Parent . . . . .	16 to 28	21.00 $\pm$ .52	12.4
$F_1$ . . . . .	(about) 20		
$F_2$ Compact group . . . . .	2 to 14	7.88 $\pm$ .25	35.5
Spreading group . . . . .	5 to 33	16.93 $\pm$ .22	25.9

The *compact* group of the  $F_2$  generation is found to have the same mean angle of deviation as the *compact* parent. The phenomenon of "shift" usually characteristic of quantitative characters is not evident. The smaller mean angle of the *spreading* group of the  $F_2$  generation as compared to the *spreading* parent would seem to indicate that the heterozygous group should have a smaller angle than the homozygous. This difference was, however, not evident for eye judgment.

The anatomy of the two types has not been studied, but a rough examination shows that in the *compact* type all the lowermost internodes are very much suppressed, and that it is impossible to trace the origin and the sequence of formation of the successive tillers. In the *spreading* type, on the other hand, the internodes are comparatively longer and the sequence of tiller formation can be made out by dissection of the parts. It is generally found that varieties with the *compact* habit do not lodge when ripe to the same extent as the *spreading* types do. De-

tailed histological investigations upon the relation between the distribution of the sclerenchymatous tissue in the stem and the *compact* and *spreading* nature assumed by the plant might prove interesting.

#### SUMMARY.

An examination of the different varieties of cultivated rice growing in the natural condition has revealed a considerable range of variation with regard to the manner of the arrangement of the tillers, and the posture assumed by the plant. Two definite types, one having a spreading arrangement, and the other a *compact* arrangement of the tillers formed, have been recognized, which have been termed *spreading* and *compact* respectively. Investigations with regard to the genetic behaviour of the two types have yielded ratios which afford ample proof of the simple dominant nature of the *spreading* over the *compact* habit.

The genetic nature of the *compact* habit having been proved to be recessive, it will be a matter of ease to fix this very desirable habit in making rice selections. The economic importance of this character will be appreciated when it is found that varieties with this habit of growth do not usually lodge badly at the time of harvest.

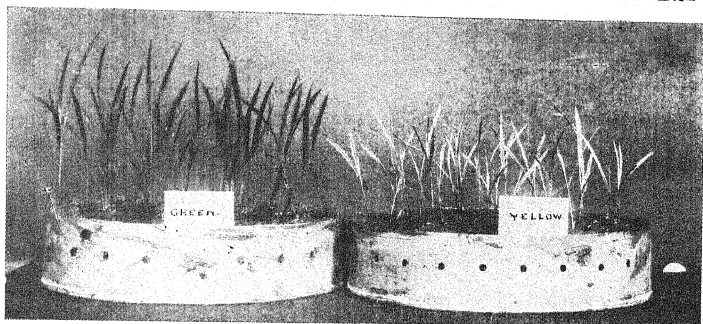
### II. Chlorophyll deficiency in Rice (*Oryza sativa*) Seedlings.

#### INTRODUCTION.

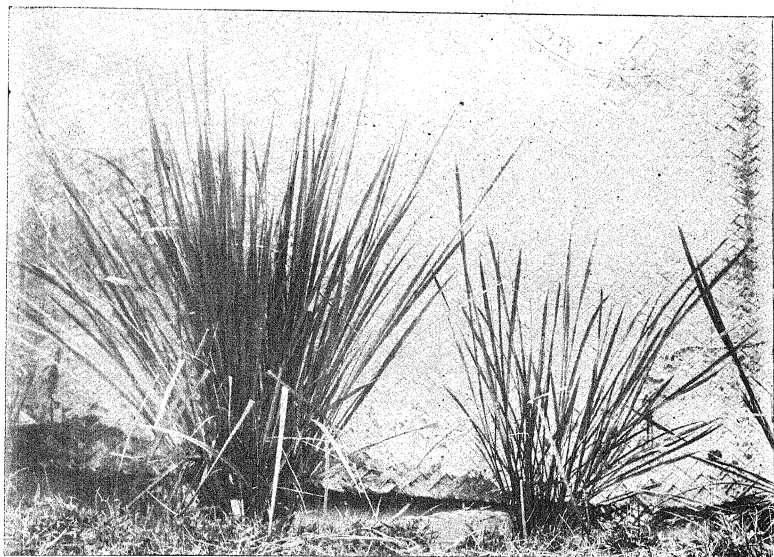
Chlorophyll deficiency in the seedlings is a common feature of several cereals and has been reported in maize, wheat, barley, etc. That such deficiency is brought about by genetic factors has been well established by work done on maize in America. In almost every case the Mendelian factor or factors responsible for this are found to be recessive. Plants heterozygous for the factors may appear green and cannot be distinguished from the homozygous green except by breeding tests. Some of these factors in their homozygous state are completely lethal in their effect on the seedlings, and necessitate the continuation of strains where such factors are present only through the heterozygous individuals, which when selfed throw the lethal albinos in the  $F_2$  generation. The normal green has always been noted to behave as an allelomorph to the various abnormalities for the chlorophyll development.

#### EARLIER WORK.

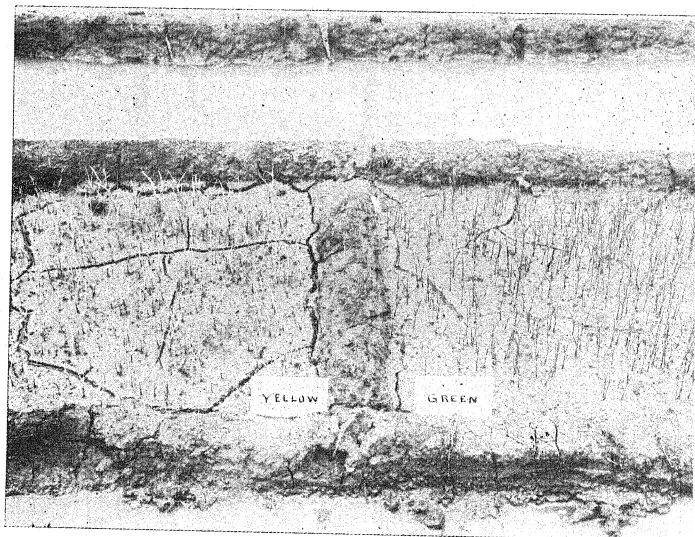
The occurrence of pure white seedlings in rice particularly in the progenies of crosses has been a common feature in the Paddy Breeding Station, Coimbatore (Plate IV, fig. 2). The manner of inheritance of this character has been a subject of study for some years. The character has been noted to be a Mendelian recessive and definite 3 : 1 and 15 : 1 ratios of green to white have been obtained together



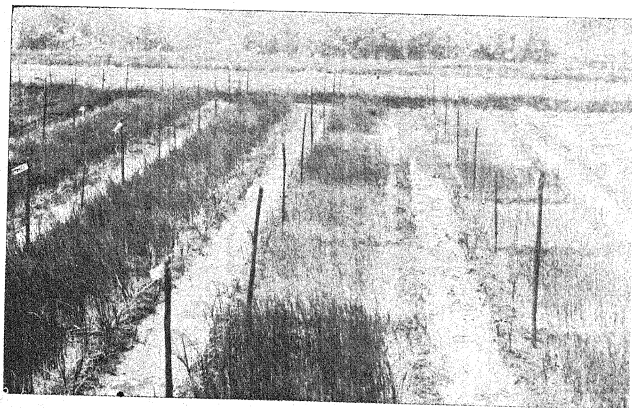
1. Two pure lines, normal green and yellow



2. Two full grown plants of the same age, green and yellow. Note the difference in size.



1. Normal green and yellow seedlings growing in adjacent beds; very early stage.



2. Same as 1; a later stage.





Two seedlings ten days old

with other more complicated ratios.<sup>1</sup> The factor or factors responsible for the occurrence of the white seedlings being completely lethal in their effect, attempts made to ascertain if there were any connections between this and characters such as colour of fertile glumes, colour of rice, etc., did not lead to anything of value. The seedlings remain healthy for a few days, and then die, without even a trace of chlorophyll formation. It must be noted, however, that the lethal factors did not interfere in any way with the formation of the anthocyanin pigment in families where factors for its development were present, as could be seen by the examination of the first leaf sheath above the ground level.

#### CHARACTER UNDER STUDY.

Apart from the pure white seedlings, the appearance of an intermediate form has been noted in rice; in this the leaves of the seedlings deficient in their chlorophyll content remain pale yellow. Unlike the white plants these intermediates grow and attain maturity like the normal greens. Their rate of growth, however, is very slow as compared to the normal greens and their size is always smaller. Though the character can be easily distinguished in the earlier stages, it gradually disappears as the plants grow older and it is difficult to distinguish a plant exhibiting yellow from a normal plant in the advanced stages of the plant except probably from its smaller size (Plate V, fig. 2).

#### SOURCE OF MATERIAL AND PROCEDURE OF WORK.

In the year 1922, in the progenies of an artificial cross done in the *white sirumani* of the Tanjore district, a few of these pale yellow seedlings were observed for the first time. Although the segregation into green and yellow was definite in the very early stages in the families in which these yellows occurred, unfortunately no counts were made. A few of these were, however, isolated, and their produce kept separate and sown in the following year. The yellows gave nothing but yellows proving the recessive nature of the factor or factors responsible for this character.

In one of the families breeding pure for yellow, a few normal green plants appeared in the seedbed, but these were easily distinguished by their deeper pigment as well as by their more vigorous rate of growth. They were suspected to be the result of natural cross pollination, as the pure yellow families had been planted by the side of the normal greens in the previous season. Eight of these suspected natural crosses were isolated for further propagation as  $F_2$  generations. They were harvested early in 1925 and under ordinary circumstances should have been sown in August which is the normal season for growing rice in Coimbatore. Instead of waiting until August, some 2,000 seeds of each of the eight families were counted and sown in March. Along with these, 2,000 seeds of three families pure

<sup>1</sup> Unpublished results collected by F. R. Parnell.

for the characters concerned were also sown to ascertain what difference there was in the viability of the seeds if such existed. All the eight families exhibited segregation and Table I gives the actual ratios obtained.

TABLE I.

*Segregation of the natural crosses.*

Family No.	Character of parents	SEGREGATION		Total seedlings obtained out of 2,000 seeds	Percentage of germination.
		Green	Yellow		
6267 . . . . .	Green .	1,209	368	1,577	78.9
6266 . . . . .	Do. .	1,332	81	1,413	70.7
6268 . . . . .	Do. .	1,458	98	1,556	77.8
6269 . . . . .	Do. .	1,725	82	1,807	90.4
6270 . . . . .	Do. .	1,465	79	1,544	77.2
6271 . . . . .	Do. .	1,413	74	1,487	74.4
6272 . . . . .	Do. .	1,553	83	1,636	81.8
6273 . . . . .	Do. .	1,602	62	1,664	83.2
368/3 . . . . .	Yellow .	..	Pure	1,443	72.2
368/4 . . . . .	Do. .	..	Do.	1,550	77.5
374/3 . . . . .	Green .	Pure	..	1,643	82.2

The ratios of seven of the eight families look alike and very probably the same pollen parent was involved in the cross. In the case of family 6267, however, the ratio obtained is different and evidently there was a different male parent in this case. It is also seen from the table that there is no significant difference in the viability of the seeds of the different families. The natural crosses do not appear to differ in this respect from the families breeding pure (the last three lines of the table). Though the separation of the greens and yellows was not very difficult, the seeds having been grown in the wrong season did not produce vigorous and healthy plants. The balance of seed left in each family was sown later in the normal season in August. The plants were now more vigorous and healthy, segregation was again manifest, but the distinction was not quite so sharp as before. When the counts were being made, another group, semi-yellow, had to be introduced which consisted of plants which were not so yellow as the typical one and at the same time

slightly less green than the typical green. It was decided to grow a further generation of some of the semi-yellows and from the experience gained to reclassify the groups. It was noticed that out of every four of these semi-yellows, one was breeding pure for yellow, while the other three segregated into greens and yellows like the greens. Table II gives the ratios with the semi-yellow group and Table III with the semi-yellows added on to the two groups, green and yellow, in the proportion of 3 to 1.

TABLE II.

Family No.	SEGREGATION		
	Green	Semi-yellow	Yellow
6267 . . . . .	1,480	250	384
6266 . . . . .	1,587	142	100
6268 . . . . .	1,840	219	106
6269 . . . . .	2,426	235	141
6270 . . . . .	1,878	204	137
6271 . . . . .	306	40	19
6272 . . . . .	1,188	150	93
6273 . . . . .	1,529	109	110

TABLE III.

Family No.	SEGREGATION	
	Green	Yellow
6267 . . . . .	1,668	446
6266 . . . . .	1,694	135
6268 . . . . .	2,004	161
6269 . . . . .	2,602	200
6270 . . . . .	2,031	188
6271 . . . . .	336	29
6272 . . . . .	1,301	130
6273 . . . . .	1,611	137

Table IV gives the totals for each of the eight families obtained in the two sowings together. Assuming that family 6267 is different from all others, the ratios of greens to yellows in the remaining seven families must represent a 15 : 1 ratio rather than anything else. Assuming that the yellows are produced by the combination of two recessive factors each of which could give identical results, it is but reasonable to expect a 15 : 1 ratio out of a cross between a yellow having both the recessive factors, and another green having both the dominant allelomorphs. If the ratios of the family 6267 be taken to represent a 3 : 1 ratio, the cross must have been between a yellow having both the recessive factors and a green having one of the two dominant allelomorphs. Taking  $C_1$ ,  $C_2$  to represent the two factors, the genetic constitution of the pollen parent resulting in the cross 6267 would be either  $C_1 C_1 c_2 c_2$ , or  $c_1 c_1 C_2 C_2$ . Families 6268 to 6273 should have resulted from a cross between parents of the constitution of  $C_1 C_1 C_2 C_2$ , and  $c_1 c_1 c_2 c_2$ .

TABLE IV.

Family No.	SEGREGATION		Ratio of green to yellow
	Green	Yellow	
6267 . . . . .	2,877	814	3.5 : 1
6266 . . . . .	3,026	216	14.0 : 1
6268 . . . . .	3,102	250	12.0 :
6269 . . . . .	4,327	282	15.3 : 1
6270 . . . . .	3,496	267	13.11 : 1
6271 . . . . .	1,749	103	17.0 : 1
6272 . . . . .	2,854	213	13.4 : 1
6273 . . . . .	3,213	199	16.1 : 1
Total for last 7 families . . . . .	21,767	1,539	14.4 : 1
Cal. 15 : 1 . . . . .	21,849	1,457	<u>Deviation</u> S. E. 2.2

## CONFIRMATORY EVIDENCE.

To obtain proof of the correctness of the constitution suggested, two sets of artificial crosses were designed, one between a normal green and a normal yellow,

two pure lines isolated from a family segregating for this character before, and the other between a pure yellow and the heterozygous green, a natural cross observed in a family pure for yellow.

*Cross I. Pure yellow*  $\times$  *pure green*. ( $c_1c_1c_2c_2 \times C_1C_1C_2C_2$ ). As expected all the  $F_1$  generation of this cross was green being  $C_1c_1C_2c_2$  and Table V gives the segregation of the  $F_2$  generations.

TABLE V.

*F<sub>2</sub>s of pure green*  $\times$  *pure yellow*.

Family No.	SEGREGATION		Ratio of green to yellow
	Greens	Yellows	
6649 . . . . .	485	34	15 : 1
6650 . . . . . (selfed material) of	461	29	
Totals for 2 families . %.	946	63	
6651 to 6686 (non-selfed) . . . . .	..	..	10.6 : 1
Total of 36 families .	14,953	1,414	

Although the ratios of the two families 6649 and 6650, both selfed material which had been grown completely, give a definite 15 : 1 ratio, the totals for the rest of the 36 families are very much out of line. For want of space and time, only a fraction of the seed had been grown in each family and added to this the difficulty experienced in the classification on account of the presence of some intermediate yellows could easily account for such bad ratios.

*Cross II. Pure yellow*  $\times$  *heterozygous green* ( $c_1c_1c_2c_2 \times C_1c_1C_2c_2$ ). The heterozygous green should produce four kinds of gametes  $C_1C_2$ ,  $C_1c_2$ ,  $c_1C_2$ , and  $c_1c_2$  which when mated to the gamete  $c_1c_2$  produced by the pure yellow should form four kinds of zygotes  $C_1c_1C_2c_2$ ,  $C_1c_1c_2c_2$ ,  $c_1c_1C_2c_2$  and  $c_1c_1c_2c_2$ . The first three would look alike, green, and the last yellow. The  $F_1$  seeds, when planted, actually gave 49 greens and 8 yellows. While all the yellows should breed pure for yellow, the greens would consist of two groups, one giving a 15 : 1 and the other 3 : 1 ratio of green to yellow. The behaviour of the  $F_2$ s proved this to be the case. (Table VI.) The three groups, however, did not occur in the  $F_2$ s according to the expected ratio

of 1:2:1. There are rather too many of the  $C_1c_1c_2c_2$  and  $c_1c_1C_2c_2$  combinations giving a 3:1 ratio of green to yellow. Whether this excess could be due to the differential dynamic activity of the pollens containing the different gametes cannot be said definitely as no investigations were carried out to elucidate the point.

TABLE VI.

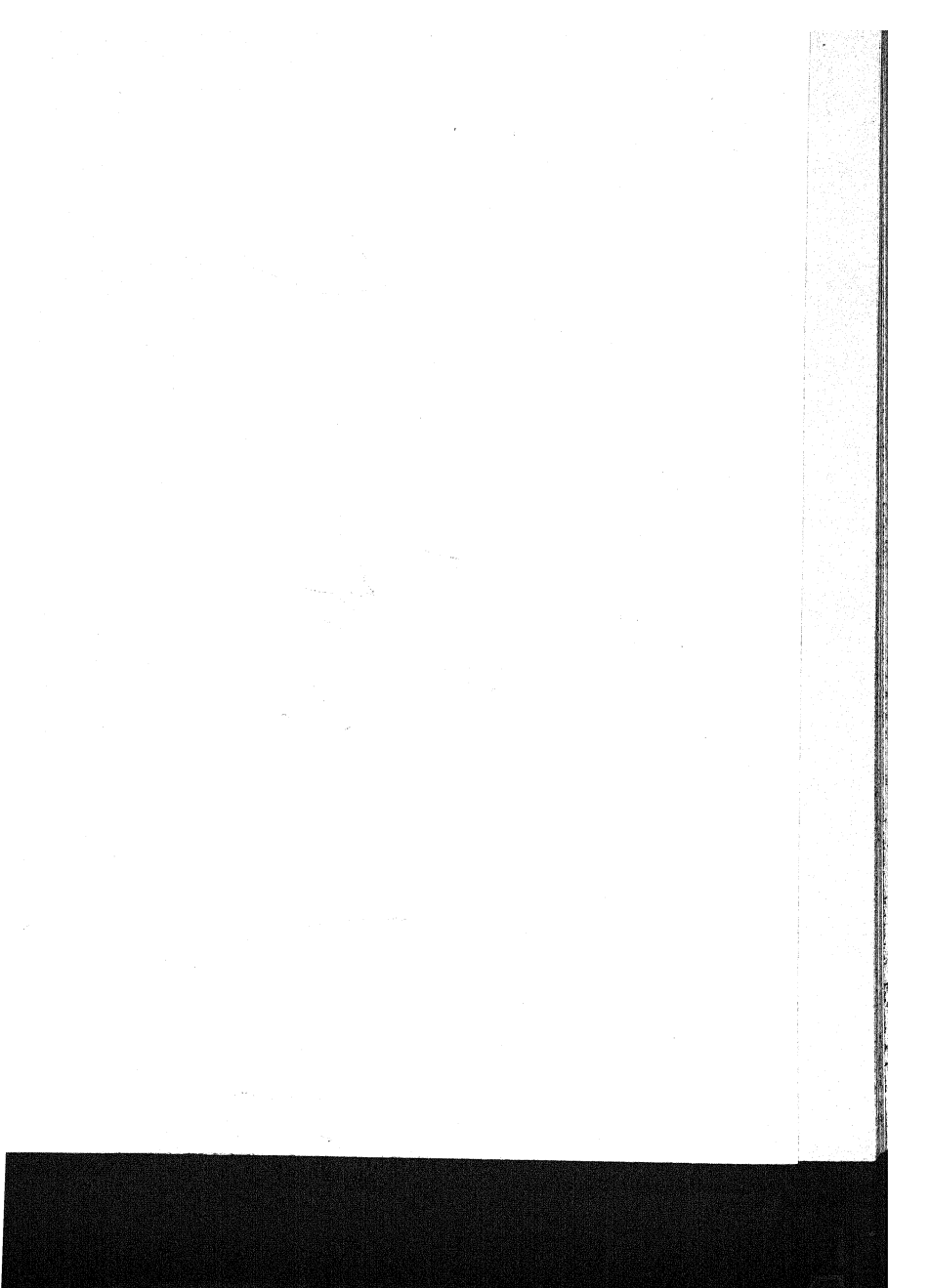
*F<sub>2</sub>s of heterozygous green × pure yellow.*

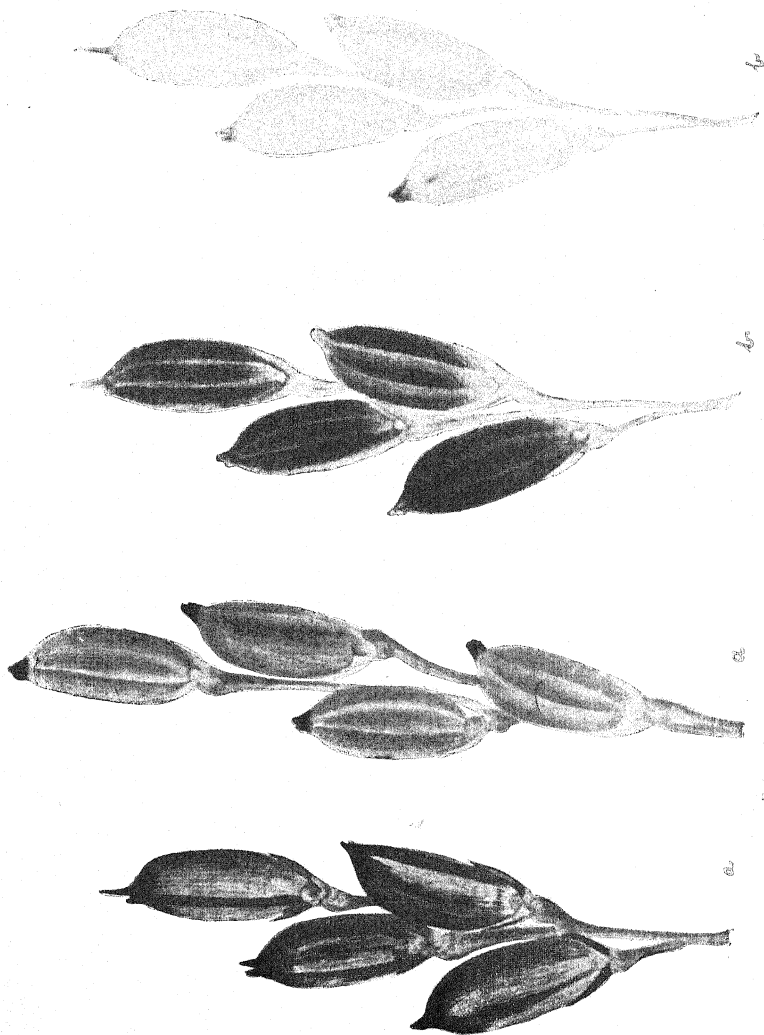
Family numbers	SEGREGATION		Ratio of green to yellow
	Greens	Yellows	
6599, 6606, 6607, 6611, 6621, 6623, 6628, 6629, 6630 and 6648 (10 families) Totals.	3,112	235	13.2 : 1
	3,138	209	15.0 : 1
6597, 6600, 6601, 6603 to 6605, 6608 to 6610, 6612, 6613, 6614, 6617 to 6620, 6622, 6624, 6625, 6627, 6631 to 6634, 6637 to 6642 and 6644 to 6647 (34 families) Totals.	8,024	3,133	2.6 : 1
	5,368	2,789	3.0 : 1

Two types of segregation can be made out, one giving a larger proportion of yellows to greens than the other. Ten families give a total of 3,112 greens to 235 yellows, and the other 34 families give a total of 8,024 greens to 3,133 yellows. These two sets of ratios could be taken to represent a 15:1 and 3:1 ratios respectively. Probably no better ratios could have been obtained when only a fraction of the seed in each family was sown, and where the character concerned is so much influenced by seasonal conditions.

## SUMMARY.

In the progenies of crosses in rice, a strain is sometimes produced, in which the young seedlings are weak, deficient in chlorophyll contents of the first few leaves, giving them a pale yellowish appearance, and rather slower in growth than the normal green. Later the differences noted in the early stages disappear, for the leaves turn a good green. This yellow when bred from behaves as a Mendelian recessive. It is possible to explain the genetic behaviour of this yellow by assuming that it is due to the combination of two recessive factors, and that each of these factors can produce identical results. If  $c_1$ ,  $c_2$ , be taken to represent these two factors, any normal green may be of the constitution  $C_1C_2$ ,  $C_1c_2$ , or  $c_1C_2$ . The first one when crossed with a pure yellow  $c_1c_2$  would give in  $F_2$ , 15 green to 1 yellow, while the other two would give 3 green to 1 yellow. The two latter greens, when





Fruit purple glaucous and green above with purple tip : (a) young stage and (b) the ripe stage.

crossed with each other, would also throw in  $F_2$ , greens and yellows, in the proportion of 15 : 1.

### III. A Note on the Occurrence of a 'Chimera' in Rice Spikelets and the Identification of a Lethal Factor

The colouring of the flowering glumes in rice varies enormously, and this is one of the main distinguishing characters of the several varieties under cultivation. The inheritance of the various colours appearing on the glumes has been under study in the Paddy Breeding Station, Coimbatore, for some years, and most of the simple cases of inheritance have already been published<sup>1</sup>. One of the most common colours of the flowering glumes noted in rice is the ordinary green colour when young, with a dark purple spot at the apex, ripening off into ordinary straw when the blackish looking tip fades away, but can still be distinguished from one which did not have the pigment at the apex. There is also another variety of glume, though not a common one, where the two flowering glumes are wholly purple almost looking black, ripening into dull violet brown.

In a cross made some years ago between two varieties having the glumes described above, the full dark purple behaved as a simple dominant over the green with the purple tip, the  $F_1$  being fully purple like the dominant parent, but with the colour slightly less intense. In this particular cross, where the progeny had been followed to several generations and several hundreds of individuals examined for the segregation of various other characters occurring in the group, so far as the glume colour was concerned, the segregation was very definite. In 1924-25 a particular selection from this progeny had been grown in the Paddy Station, and this was found to segregate for glume colour, purple, and green with the purple tip. In this family a plant was accidentally met with wherein the full purple and the green glumed spikelets, which ought to occur normally in different plants, were occurring together in the same panicle, and even in the same spike. The plant had all the other characters which occur associated with the full purple flowering glumes, and had several panicles with normal full purple glumes, three panicles with the green and purple glumes occurring together as individual spikelets, and one panicle where all the spikelets were green. This was a phenomenon never noted before. It proved on further analysis to be a simple case of *chimera*.

The plant was carefully marked, and the seeds gathered for further trials. The grains in the panicles exhibiting the chimeral condition were separated into green and purple, and sown separately in the following season. For comparison, a small quantity of seeds from the normal purple and normal green glumes were also sown along with these.

The green glumed grains occurring in the purple glumed plant, behaved just like the purple glumed grains in that they segregated and gave the two types, where-

<sup>1</sup> Farnell, F. R., Rangaswami Ayyangar, G. N., and Ramiah, K. The Inheritance of Characters in Rice, *Mem. Dept. Agri. India, Bot. Ser.* Vol. IX, No. 2; XI, No. 8.

a3, the green grains from a normal green plant bred true to green. Details about the plant showing the chimera were as below :—

One panicle with 96 purple, and 101 green glumed spikelets,  
 a second panicle with 23 purple, and 129 green glumed spikelets,  
 a third panicle with 136 purple, and 50 green glumed spikelets,  
 a fourth panicle with all green glumed spikelets,  
 and a number of other panicles with the ordinary full purple glumed spikelets.

A small number of grains from each head were sown in the following season and the results obtained are mentioned in the Table below :—

		Plants with	
		Purple glumes	Green glumes
Grains with purple glumes from .	{ Head No. 1 gave .	10	5
	„ „ 2 „ .	5	1
	„ „ 3 „ .	41	14
		56	20
Grains with green glumes from .	{ Head No. 1 gave .	20 (a)	16 (b)
	„ „ 2 „ .	7	3
	„ „ 3 „ .	10 (c)	7 (d)
	„ „ 4 „ .	30	12
		67	38
Normal purple glumed grains from other panicles in the same plant.		84	49

Some further selections were made in families marked (a), (b), (c) and (d), in the above table and a further generation raised from them. While selections (b), and (d) bred true to green glume, (a) and (c) segregated and gave the two types in almost similar proportions.

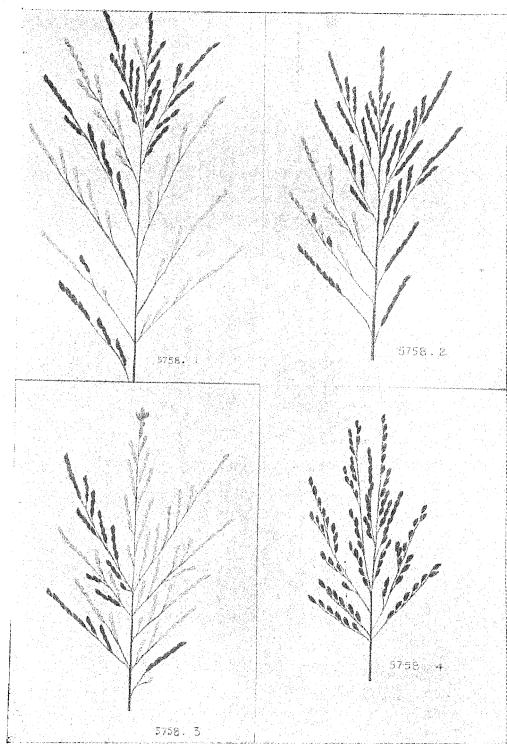
The above genetic evidence indicates that the change involved in the production of pigment over the fertile glumes was confined to the epidermal layer and not to the hypodermal layer, from which ovules and pollen grains are derived. Histological examination shows that the colouring matter is confined to the cells of the



1. Two kinds of ripe panicles.



2. Panicles exhibiting *chimera*.



Diagrammatic representation of the panicles that exhibited the *chimera*.

epidermis. Although the glumes are green, the fertilised egg cell is heterozygous, and the developing grain thus behaves like the one with purple glumes.

While the evidence that the purple and green glumes behave as a simple pair of allelomorphs is very definite, the above chimeral condition of the two types appearing on the same plant can only be explained as due to a factor mutation in a somatic cell, and that the mutation must have occurred late in ontogeny that only the epidermal layer was affected. Some cases of chimera have been explained that the whole chromosome carrying the particular factor was lost from a cell at an early stage in the development of the plant. This explanation cannot possibly fit in with the present case. It has been noted in this family that the purple glume is associated with a deeply pigmented internode, and the green glume with a lighter coloured internode. It is possible that either the same factor which produces deep purple pigment on the glumes is also responsible for the deeply pigmented internode, or, the factors are separate but present in the same chromosome closely linked. Since the panicle No. 4 which had all green glumes had the deeply pigmented internode, it is almost certain that there are two separate factors, and that there has been a factor mutation from *G*, responsible for the full purple glume, to *g*, responsible for the green glume.

It may be noted from the ratios given of the plants with full purple glumes and those with the green glumes in the family that exhibited the chimera, that it is a 2 : 1 (207 : 107) instead of a 3 : 1. This led to the tracing back of the history of the family, and this revealed some interesting results. The two varieties which formed the parents of the original cross are described below :—

Character	T. 1359	T. 264
Leaf sheath . . . . .	Very slight purple pigment, looking almost green . . . . .	Good purple with purple lines.
Sheath axil . . . . .	No pigment . . . . .	Deeply pigmented.
Internode . . . . .	Very dark purple, looking black . . . . .	Ordinary purple lines only.
Septum . . . . .	Dark purple . . . . .	Pinkish.
Auricle and Ligule . . . . .	Dark purple . . . . .	No pigment.
Sterile glumes . . . . .	Purple . . . . .	No pigment.
Flowering glumes . . . . .	Dark purple, getting black when old, like the internode . . . . .	Ordinary green, with purple pigment at the apex only.
Stigma . . . . .	Slightly pigmented, in only a few feathers . . . . .	Dark purple looking black.
Rice . . . . .	Black (glutinous) . . . . .	White (non-glutinous).

Each set of characters mentioned above behave as a simple pair of allelomorphs, the character of the T. 1359 parent being the dominant in every case except the stigma, where the dark purple stigma of T. 264 is dominant over the other. The  $F_2$  had all the characters of T. 1359, with this difference, that the intensity of the pigment over the fertile glumes and the internodes was much less than in T. 1359.

The  $F_2$  segregated in a simple way giving only two groups like the two parents with a close 3 : 1 ratio as shown below :—

Total for 20 families made up of—	Like T. 1359	Like T. 264
20 $F_{2s}$ , and 13 $F_{3s}$ . . . . .	8,647	2,901
Calculated 3 : 1 . . . . .	8,561	2,887

It was possible, however, to make out the heterozygous group, in that it had the purple stigma of T. 264, and had a rather lighter pigmented internode and fertile glume than the homozygous group. Even as regards rice, the segregation was complete, in that all the plants with the green glumes had white rice, and those with purple glumes, purple rice of different shades. Since none of the purple rices found associated with the dark purple internode and purple glumes had the same intensity as that of T. 1359 parent, in one of the  $F_3$  families an attempt was made to classify the rices into different degrees of purple, and selections were made from the same to raise an  $F_4$ . Out of several hundreds of plants examined for rice, one *cross-over* plant was obtained having dark purple internode, full purple glume, and white rice. This plant when bred from gave

Dark internode and full purple glume	Light internode and green glume with purple tip
341	163

both the groups, however, having only white rice. The above ratio will have to be taken as a 2 : 1 rather than anything else. A number of selections were made in the first group and three more generations raised therefrom. In every case the selections segregated and gave the two groups again as shown below :—

Family Nos.	Dark internode, purple glume	Light internode, green glume
$F_5$ . . . 5106 and 5109 . . . .	67	36
$F_6$ . . . 5740 to 5757 . . . .	1,174	712
$F_7$ . . . 6360 to 6362 . . . .	162	98
Totals for 23 families . . . .	1,403	846

Since by repeated selections a homozygous plant with purple glume and white rice was never obtained, and the ratio of purple glume to green glume represents a 2 : 1, the possibility is that with the cross-over for the rice character, a lethal factor has been brought in, which prevents the formation of the type homozygous for the glume. Taking G to be the factor for purple glume, and g for green glume, we

should get three kinds of zygotes, GG, Gg, and gg, in the proportion of 1 : 2 : 1 ; but the zygote GG never appears to be produced, resulting in a 2 : 1 ratio of purple glume to green glume.

The lethal effect in the zygote can manifest itself in any one of the following ways :—

- (1) aborted seeds,
- (2) seeds do not germinate, and
- (3) seeds germinate but the plants die off.

Of the above, the last two possibilities have to be ruled out, since either defective germination in the seed beds, or plants dying off in numbers later, could not have escaped observation with such intensive studies. It is more than probable that the zygote GG resulted in aborted seeds in the present case, and this is strengthened by the observation that the purple glumes of this group always gave a large percentage of unset chaffy grains, much more in comparison with those with green glumes. Unfortunately, nothing more could be done in this family as the whole material had been lost when the author was away in England.

Use has been made in the preparation of this last note of some of the unpublished material collected by Parnell when he was the Government Economic Botanist at Coimbatore, and the author is indebted to him for the same.



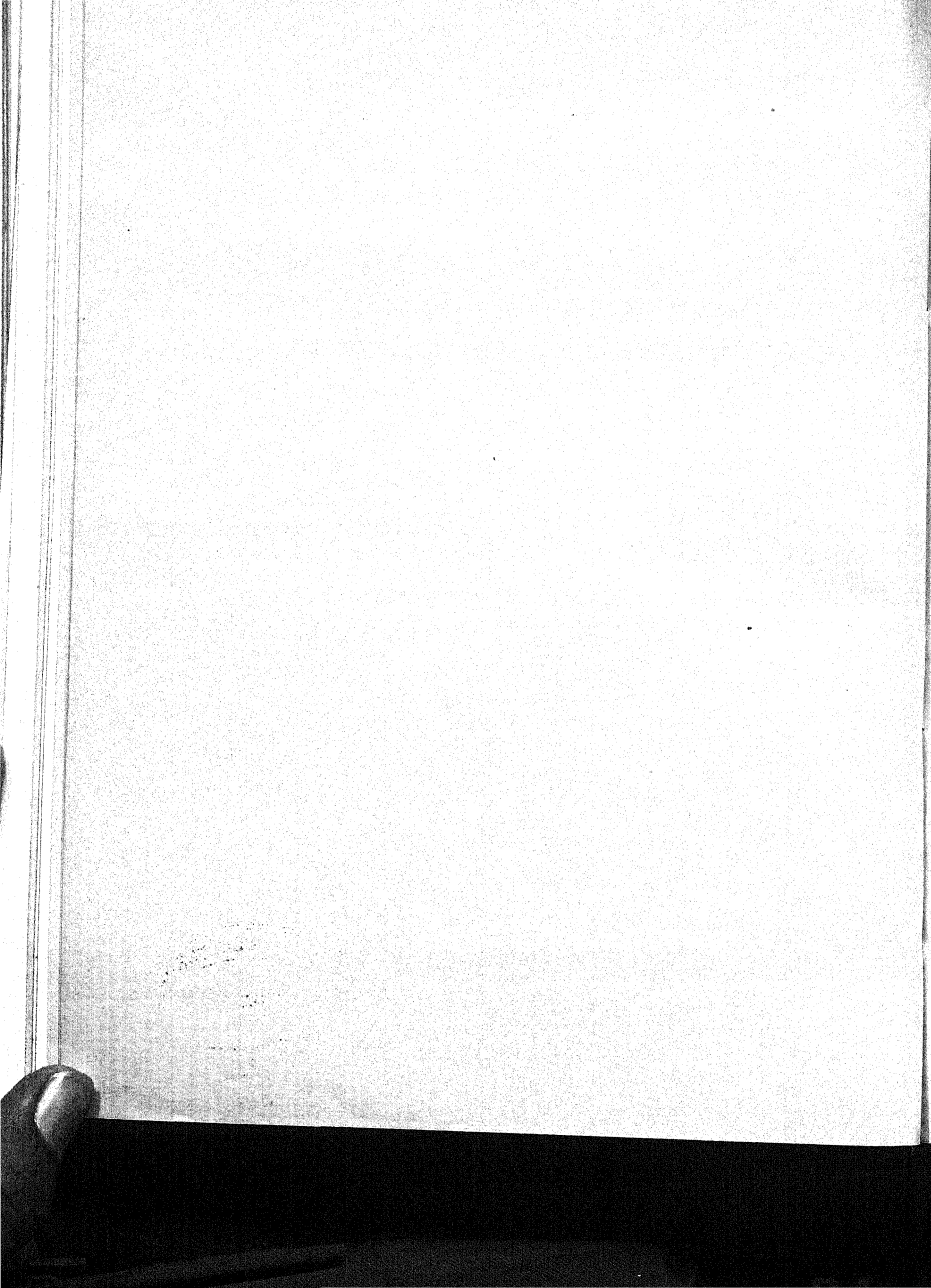
## PREFACE.

The first two parts of this series appeared under the pen of F. R. Parnell, then Economic Botanist to the Government of Madras. The third part, by K. Ramiah, recorded the results obtained by him during the period he was in charge of the Section.

This, the fourth part, takes up the story of the work done on the Paddy Breeding Station, Coimbatore, to settle doubtful points or to continue unfinished enquiries that remained when Parnell left India in 1924. Parnell and his co-workers share the credit of the initiative, and to K. Ramiah fell the lot of carrying on the temporary control of the Section until R. O. Iliffe succeeded at the end of 1925.

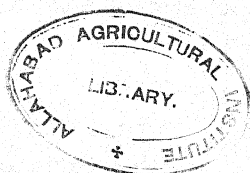
This part, then, records the work done by K. Ramiah and others during this interim period and includes portions of work done on Sections II and VIII in 1926-27 during Iliffe's régime.

Acknowledgments are also due to C. R. Sreenivasa Ayyangar, Superintendent, Agricultural Research Station, Maruteru, for his share in Sections III, IV, and V, and to M. Anandan, Superintendent, Agricultural Research Station, Pattambi, for his share in Section I, who during their stay in Coimbatore as assistant to Parnell contributed in no small measure to the investigations contained in the said Sections. [K. R.]



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# INHERITANCE OF CHARACTERS IN RICE, PART IV.

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## I. The glutinous character of the endosperm in rice.

### INTRODUCTION.

Parnell<sup>1</sup> has recorded the occurrence of segregation in the rice pollen which gives the same reaction with iodine as does the glutinous and non-glutinous endosperm of the rice. The study of the glutinous and non-glutinous pollen grains in the pollen sac of the  $F_1$  plant, which represents the results of Mendelian segregation, has given convincing evidence as to the normality of the microgenesis, the two types of pollen being formed with equal frequency. When, however, the  $F_1$  plant is allowed to self-fertilize, and the resultant grains are counted, there is always a slight excess of non-glutinous grains, the deviation from the normal 3 : 1 ratio of non-glutinous to glutinous being very often significant in terms of the standard error. When an  $F_2$  is raised, we get the usual three types of plants, one with the non-glutinous grain, a second with both non-glutinous and glutinous grains, and a third with glutinous grain. The ratio in which these three types occur, however, shows a considerable departure from the expected 1 : 2 : 1 ratio. Results obtained at Coimbatore and by other workers elsewhere have shown definitely that the glutinous and the non-glutinous character of the endosperm form a simple pair of Mendelian allelomorphs. There are, however, some disturbing factors influencing the ratios in the  $F_2$  and later generations. The results here recorded relate to the investigations carried out at the Paddy Breeding Station, Coimbatore, to find out such disturbing causes.

<sup>1</sup> Parnell, F. R. (1921). Note on the detection of the segregation by examination of the pollen of rice. *Jour. of Genetics*, Vol. XI, No. 3.

## DIFFERENTIAL ACTIVITY OF THE POLLENS.

Lien Fang Chao<sup>1</sup> has been tackling the same problem and his results have been published recently. He has brought forward data to show that this significant deficiency of the glutinous character in the  $F_2$  is due to the accumulation of many small deviations in the same direction. The microsporogenesis being normal, the observed deficiency of the glutinous grains in the  $F_2$  seeds can only be accounted for by any differential rate of activity of the two kinds of pollen in fertilizing the ovum, as has been observed by Brink and Macgillivray<sup>2</sup> in the case of the waxy character of the endosperm in maize. The only way to elucidate this point is to make back crosses, which Lien Fang Chao considers impracticable in rice. This line of attack of the problem engaged our attention from the very beginning, but the number of crossed seeds obtained with the crossing technique in vogue at the Paddy Station was never large enough to prove the point. As the result of a better crossing technique evolved at the station at a later date,<sup>3</sup> the back crossing method was resorted to on a large scale in the season 1924-25. Every time an unpigmented plant with the glutinous pollen was kept as the female parent, and the emasculated spikelets were pollinated with the dimorphic pollen from a pigmented plant. All the resultant seeds were grown in the following season, and even in the early stages the unpigmented plants were pulled out as non-crosses, retaining only the pigmented plants. These  $F_1$  plants were allowed to set seed normally. Out of crosses made on 13 plants, 220 really hybrid plants resulted. Of these, 125 resembled the usual  $F_1$ , in having both non-glutinous and glutinous grains, while the other 95 were pure for glutinous grain. Assuming that the two kinds of pollen are equal in their activity in fertilizing the ovum, the chances are that we should get half and half of  $F_1$  like plants and pure glutinous plants. The deviation from this expected ratio is in this case twice the standard error and hence cannot be taken as a conclusive proof of the weaker fertilizing activity of the glutinous pollen. The results, however, show a distinct possibility of the glutinous pollen being weaker in its dynamic activity.

## INFLUENCE OF ENVIRONMENTAL CHANGES ON SPOROGENESIS.

Investigations were also carried out to find out whether the regularity of the sporogenesis can be upset by changing the environmental conditions under which the  $F_1$  plants were growing. A number of such plants growing in the field were removed just before they had reached their reproductive phase, and subjected to treatments which were in the way of starving the plants of their normal food supply, either by drastically cutting the supply of light to prevent the photosynthetic activity, or growing them in well water and distilled water to starve them of mineral

<sup>1</sup> Lien Fang Chao (1928). The disturbing effect of the glutinous gene in rice on a Mendelian ratio. *Genetics*, Vol. 13, No. 3.

<sup>2</sup> Brink, R. A., and Macgillivray, J. H. (1924). Segregation for the waxy character in maize pollen and differential development of the male gametophyte. *Amer. Jour. Bot.*, 11.

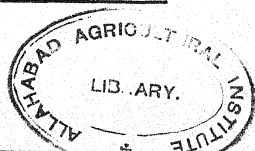
<sup>3</sup> Ramiah, K. (1927). Artificial hybridisation in rice. *Agri. Jour. of India*, Jan, 1927.

matter and nitrogen, or by defoliating them to reduce the area of photosynthetic activity. The treatments really told on the plants as evidenced by the fact that in the case of plants grown in the dark most of the flowers were not able to produce pollen grains or to lay down starch or gluten in the grains that might have been formed. Nearly 400 tubes of flowers were collected and preserved in alcohol-formalin solution for later work in the laboratory. A large number of pollen sacs were examined under the microscope, tested with iodine, and counts made of the glutinous and non-glutinous grains. Table 1 gives the summary of results.

TABLE I.

*Influence of environment on the formation of non-glutinous and glutinous pollen grains in the anther sacs of  $F_1$  plants.*

No.	Nature of treatment	Number of counts	TOTAL NUMBER OF POLLEN GRAINS		Deviation from 1:1 ratio	Standard error	DEVN. S. E.
			Non-glutinous	Glutinous			
I	Floating the plants in a frame inside a well.	21	10,074	9,861	100.5	70	1.5
II	Ditto	11	3,581	3,441	70.0	42	1.7
III	Plants in pots in a dark room	12	6,392	6,295	48.5	56	0.9
IV	Plants in bottles containing well water placed in dark room.	37	14,850	15,010	80.0	86	0.9
V	Plants defoliated at junction of blade, in fields.	8	2,123	2,135	6.0	33	0.2
VI	As in V but plants more advanced in age.	34	14,131	13,825	153.0	84	1.8
VII	Plants defoliated and floated in well, as in I.	12	4,808	4,647	80.5	49	1.6
VIII	Ditto	18	6,988	6,742	123.0	59	2.1
IX	Plants defoliated and grown in bottles containing well water placed in the open.	39	10,287	9,728	279.5	71	3.9
X	As in IX, but heads already formed in most tillers.	18	10,047	9,958	44.5	70	0.6
XI	As in IX, but plants placed inside a glass house.	17	7,112	6,569	71.5	59	1.2
XII	As above, but plants more advanced in age.	9	2,191	2,156	17.5	33	0.5
XIII	Plants in bottles containing distilled water placed inside a glass house.	7	3,816	3,829	6.5	44	0.1
XIV	Plants grown in the wrong season, subject to winter cold.	36	22,423	21,774	324.5	105	3.1
	Counts of controls in IX and XIV	4	1,661	1,634	13.5	28	0.5



The glutinous grains are found to be less than 50 per cent. in several cases as the result of the treatments. In the case of treatments VIII, IX and XIV, the deviation from the normal 1 : 1 ratio is more than twice the standard error. It is almost certain that treatments IX and XIV have affected the development of the glutinous pollen in that the deviations are more than 3 times the standard error, whereas in the case of the controls kept for comparison, the deviation was only half the error. The pollen counts were made separately for the anther sacs collected from spikelets situated in different parts of the panicle namely, top, middle, and bottom, and there was no perceptible difference among them. These results go to prove that there is some inherent defect in the glutinous gene, and that environmental factors can affect its expression. Chang's results also confirm our observations. It must be noted, however, in contrast with Chang's results that in no case was the number of rice grains with the glutinous endosperm in the  $F_1$  plant more than one-third of those with non-glutinous endosperm.

#### RELATIONSHIP BETWEEN ENDOSPERM CHARACTER AND VIABILITY OF SEEDS.

When the  $F_2$  is raised, we get the three groups of plants, one group pure for the non-glutinous endosperm breeding pure subsequently, a second group heterozygous for the glutinous character like the  $F_1$  and always segregating for the character, and a third group pure for the glutinous endosperm breeding pure subsequently. The percentage ratios in which these three groups occur are far out of the normal 25 : 50 : 25 as in Table II, which includes figures from several unrelated families.

TABLE II.

*Ratios of pure glutinous, heterozygous for glutinous, and pure non-glutinous plants in the  $F_2$ s of some crosses.*

No.	Groups	Number of families examined	Non-glutinous	RATIOS	Glutinous
				Heterozygous	
1	Black glutinous rice $\times$ white non-glutinous rice.	39	4,195 <i>35.2</i>	5,788 <i>48.6</i>	1,936 <i>16.2</i>
2	Black glutinous $\times$ red non-glutinous rice.	24	1,667 <i>33.8</i>	2,407 <i>48.7</i>	864 <i>17.5</i>
3	White non-glutinous $\times$ white glutinous rice.	13	2,053 <i>30.1</i>	3,416 <i>50.1</i>	1,353 <i>19.8</i>
4	Black glutinous $\times$ white non-glutinous rice.	5	1,296 <i>30.3</i>	2,118 <i>49.4</i>	868 <i>20.3</i>
	TOTAL	81	9,211 <i>32.9</i>	13,729 <i>49.1</i>	5,021 <i>18.0</i>

(N.B.—Figures in italics represent the percentages of the different groups.)

Parnell<sup>1</sup> suggested differential germination and dying off as probable causes of this deviation. To test this point, the percentage of seeds sown that gave plantable seedlings was determined for each of the three groups in 100 selections of an  $F_2$  segregating for the endosperm character. There was no indication of any connection between the glutinous character and the percentage of germination. In the heterozygous group of the above, where the percentage of germination varied from 64 to 93, half a dozen families in each of the high and low percentages of germination, were planted separately and the rices were examined individually for the plants, at harvest time. This test also did not give any definite indication.

To test the point of differential germination rather more critically, in the season 1920-21 5  $F_1$  plants were harvested separately. The produce of each plant was carefully examined in the laboratory, and separated into glutinous and non-glutinous grains, by cutting a small bit of the grain at one end, and testing the same with iodine. The two types of grains thus separated were counted and sown separately in uniformly prepared seed beds. The resultant seedlings were counted in each plot and the percentage of germination worked out in each case (Table III).

TABLE III.

*Comparative germination of  $F_2$  grains with non-glutinous and glutinous endosperm.*

Family No.	PERCENTAGE OF GERMINATION OF GRAINS WITH	
	Non-glutinous endosperm	Glutinous endosperm
2701 . . . .	76.2	56.0
3297 . . . .	68.0	57.0
3298 . . . .	56.8	58.6
3299 . . . .	71.8	40.0
3300 . . . .	75.6	42.6
Means . . . .	70.0 $\pm$ 2.1	51.0 $\pm$ 2.8

<sup>1</sup> loc. cit.

The standard error of comparing the two means is 4.7. The actual difference between the two means ( $70-51=19$ ) is more than three times the error and hence can be taken as significant.

In the following season the produce of another four  $F_1$  plants was first sown in the seed-beds, and after the lapse of a week, all the germinated seedlings were collected and separated into glutinous and non-glutinous types by testing the unused endosperm in each grain with iodine. The results of this test are given below (Table IV).

TABLE IV.

*Relation between germination and endosperm character.*

Family No.	NUMBER OF SEEDLINGS OBTAINED		Ratio of non-glutinous to glutinous	Percentage of glutinous to the total
	Non-glutinous	Glutinous		
3672 . .	560	147	3.8 : 1	20.8
3673 . .	701	192	3.7 : 1	21.5
3676 . .	292	68	4.3 : 1	18.9
3677 . .	609	143	4.3 : 1	19.0
TOTALS .	2,162	550	3.9 : 1	20.3

In every case the deviation from the expected 3 : 1 ratio is more than three times the standard error, and the percentage of pure glutinous to the total is far less than that of the glutinous grain in the  $F_1$  plants of related families. The above two tests give a definite indication that the grains with the glutinous endosperm are less viable than those with the non-glutinous one, thereby proving that this differential viability may be one of the main causes of the distorted ratios obtained in the  $F_2$ s.

To test the connection between the glutinous character of the endosperm in the grains, and the vigour of the seedlings obtained from such grains, the seedlings in another 8 families of  $F_2$  selections, heterozygous for the glutinous character, were first separated into three different categories, (i) strong and tillered seedlings, (ii) strong seedlings but with no tillers, and (iii) weak seedlings with no tillers. The groups were transplanted separately, and the plants examined individually for the endosperm character at harvest time. The results are given in Table V.

TABLE V.

*Connection between the vigour of seedlings and the endosperm character.*

Family No.	STRONG AND TILLER-ED SEEDLINGS			STRONG BUT NOT TILLER-ED SEEDLINGS			WEAK AND NON-TILLER-ED SEEDLINGS			TOTAL		
	Non-gluti-nous	Hete-rozy-gous	Gluti-nous	Non-gluti-nous	Hete-rozy-gous	Gluti-nous	Non-gluti-nous	Hete-rozy-gous	Gluti-nous	Non-gluti-nous	Hete-rozy-gous	Gluti-nous
2828	48	75	30 <i>19.6</i>	35	52	37 <i>29.8</i>	20	25	8 <i>15.1</i>	103	152	75 <i>22.7</i>
2838	35	47	28 <i>25.5</i>	23	44	24 <i>26.4</i>	12	22	6 <i>15.0</i>	70	113	58 <i>24.1</i>
2839	53	68	25 <i>17.1</i>	17	40	17 <i>23.0</i>	9	14	4 <i>14.8</i>	79	122	46 <i>18.6</i>
2841	61	96	31 <i>16.5</i>	34	53	20 <i>18.7</i>	20	26	10 <i>17.9</i>	115	175	61 <i>17.4</i>
2843	43	64	31 <i>22.5</i>	31	56	18 <i>17.1</i>	15	28	21 <i>32.8</i>	89	148	70 <i>22.8</i>
2861	43	84	22 <i>14.8</i>	36	60	34 <i>26.2</i>	12	9	10 <i>32.3</i>	91	153	66 <i>21.3</i>
2864	65	100	24 <i>12.7</i>	33	39	20 <i>21.7</i>	15	25	27 <i>40.3</i>	113	164	71 <i>20.4</i>
2866	59	76	13 <i>8.8</i>	45	75	33 <i>21.6</i>	12	23	12 <i>25.5</i>	116	174	58 <i>16.7</i>
2869	48	72	33 <i>21.6</i>	19	24	11 <i>20.4</i>	9	3	3 <i>20.0</i>	76	99	47 <i>21.2</i>
TOTALS	455	688	237 <i>17.2</i>	237	443	214 <i>23.0</i>	124	175	101 <i>25.3</i>	852	1300	552 <i>20.4</i>

(N.B.—Figures in italics represent the percentage of the glutinous plants to the total.)

It is found that there is a progressive increase in the percentage of the pure glutinous plants with the poorer condition of the seedlings at the time of transplanting. It should therefore appear that the glutinous endosperm of the grain is associated with lack of vigour in the seedling growing from it.

#### ASSOCIATION OF THE GLUTINOUS CHARACTER WITH OTHER GENETIC CHARACTERS.

In the groups mentioned in Table II where they were segregating for the endosperm character, the families were segregating for several other genetic characters like colour of rice, colour of glume and palea, duration, height of plants, etc., and there was no apparent connection between the endosperm character and any of the

other characters mentioned above. But in group 3 the family was segregating for the presence and absence of pigment in the leaf axil and apiculus. Table VI below gives the tabulation of this group when the pigment character and the endosperm character are taken together. It shows a definite linkage between the pigment factor and non-glutinous character of the endosperm.

TABLE VI.

*Association of glutinous character with the presence of pigment in the leaf axil and tip of fertile glumes.*

Family	TOTAL PLANTS WITH			PLANTS WITH PIGMENT AT LEAF AXIL AND PALLEA TIP			PLANTS WITHOUT ANY PIGMENT		
	Non-glutinous	Heterozygous	Glutinous	Non-glutinous	Heterozygous	Glutinous	Non-glutinous	Heterozygous	Glutinous
1880 group . . .	2078	3571	1336	1120	2846	1227	958	725	109
Percentage of glutinous types to the total.	..	..	19.1	..	..	23.6	..	..	6.1

Although the presence of pigment in the different parts of the rice plant is controlled by several mendelian pigment localization factors, it has been shown that to produce any pigment two complementary factors must be present. Inheritance studies in Coimbatore have shown that one of these main pigment factors is itself responsible for the production of pigment in the leaf axil and apiculus. The linkage referred to here is with this main pigment factor as distinguished from several other localization factors. This point will be discussed in greater detail when dealing with the several linkage groups.

## SUMMARY.

The glutinous and the non-glutinous characters of the rice endosperm form a simple pair of allelomorphs. The two kinds of pollen, glutinous and non-glutinous, are found to occur with equal frequency in the  $F_1$  plant; yet, when the plant is allowed to self-fertilize and the resultant seeds are examined for the endosperm character, the glutinous number is found to be deficient and the deviation from the normal 3 : 1 ratio is often significant in terms of the error. To test the dynamic activity of the two kinds of pollen in fertilizing the ovum, back crossing was resorted to. Though the results have not been quite confirmatory, there is an indication that the glutinous pollen is weaker in its action similar to what has been observed in the case of the waxy endosperm character in maize.

Certain experiments were carried out to find out whether environmental conditions can affect the normality of the sporogenesis in the  $F_1$  plant. When the plants were subjected to drastic treatments like defoliating them and growing them in

pure water cultures, or growing them in the wrong season—cold weather, the normality was upset in that the pollen counts in the anther sac showed a great deficiency of the glutinous type, the deviation from the normal 1 : 1 ratio of non-glutinous to glutinous pollen being significant in terms of the error. The experiments prove that there is some inherent defect in the glutinous gene and that environmental conditions can affect its expression.

When the  $F_2$  seeds are grown again there is a further deficiency in the pure glutinous types. Certain experiments carried out to test the point of differential germination and dying off have shown that under normal conditions, grains with glutinous endosperm are less viable than the non-glutinous. There is also an indication of a connection between the glutinous endosperm character of the grains and the vigour of the seedlings obtained from them.

Among various genetic characters studied along with the glutinous endosperm character, there is found a close linkage between this character and one of the two main pigment complementary factors which is responsible for the development of pigment at the leaf axil and palea tip.

## II. Inheritance of size and shape of grain in rice.

### INTRODUCTION.

Size and shape of grain are familiar characters. They correspond roughly to the size of the kernel, the two varying together. The size of the grain or kernel can be easily measured and the shape can also be described by the examination of the lemma and palea. The size and shape have been used by almost every one who has attempted classification of rices, as one of the diagnostic characters. It is easy to recognize three broad groups, round, medium, and long. Kikawa<sup>1</sup> in his classification of the Burma rices has tried to distinguish six groups of shape. Graham<sup>2</sup> working with the rices of the Central Provinces, has recognized five groups taking into account the shape of lemma and palea together. His five groups are :—

- (i) glume and palea slightly convex, (ii) glume and palea convex, (iii) glume and palea very convex, (iv) glume slightly convex, palea convex, and (v) glume slightly convex or straight, palea straight or slightly concave.

He also divides the size of the spikelets into four groups :—

- (i) long spikelet in which the length is more than four times the breadth, (ii) fine, in which the length is more than three times the breadth, (iii) coarse, in which the length is more than twice the breadth, and (iv) round, in which the length is less than twice the breadth.

He records that any attempt to give definite measurements has ended in failure.

<sup>1</sup> Kikawa, S. Classification of rices in Burma. *Jour. Agri. Imp. Univ. Tokyo*, III, No. 2.

<sup>2</sup> Graham, R. J. D. (1913). Preliminary note on the classification of rice in the Central Provinces. *Memoir Dept. Agri. India, Bot. Series*, Vol. VI, No. 7.

## SOURCE OF MATERIAL AND PROCEDURE OF WORK.

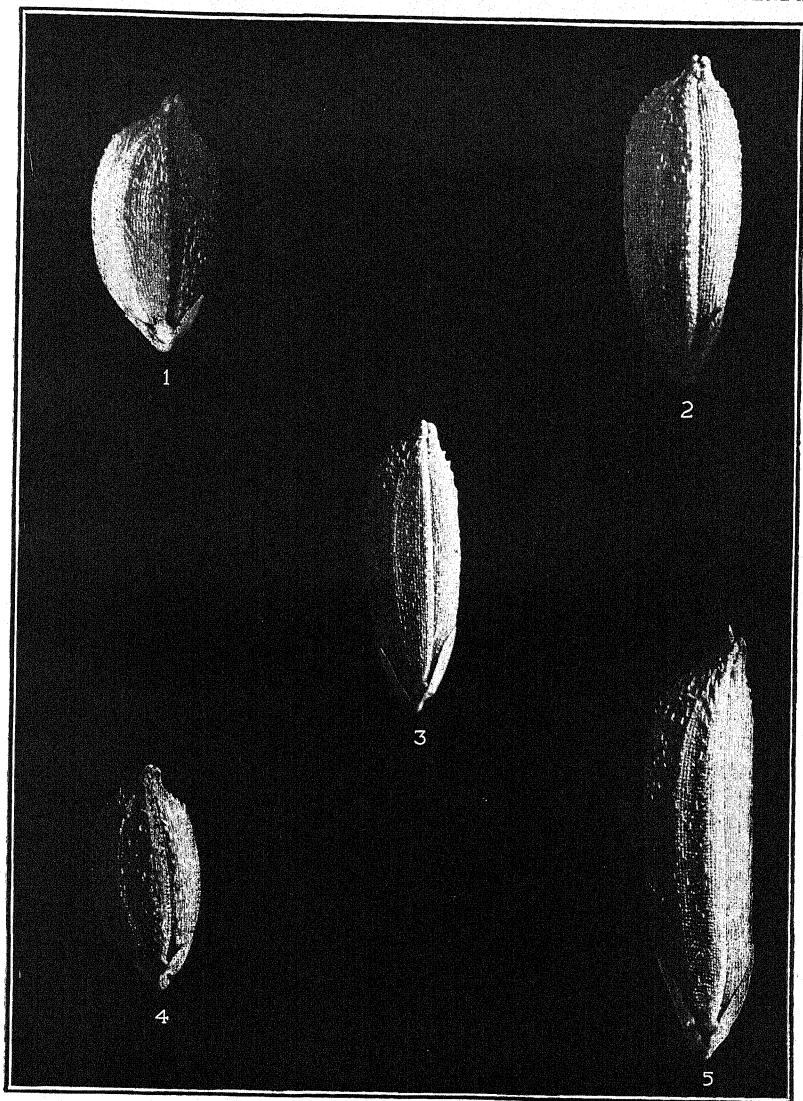
The study of several natural crosses segregating for the size of grain had given indications that the inheritance of grain size was rather complicated. Only one case occurred where its inheritance proved to be very simple, and the results herein recorded refer to this single case. The case referred to includes the study of inheritance of the size of grain meaning thereby the length of the spikelet, and also the shape of the grain. One of the parents involved in the cross, *sirumani* (Plate I, fig. 1) has the characteristic round shape of grain corresponding to group (iii) of Graham's classification in that the lemma and palea are very convex. The length of the spikelet is very short, under 6 mm. The other parent *anaikomban* (Plate I, fig. 2) has the ordinary long type of grain corresponding to group (i) of Graham's classification, glume and palea slightly convex, with a spikelet length of about 8.5 mm.

In the year 1922-23, in a bulk crop of the long grain, a few aberrant types were noted with all the characters of the type except in the size of the grain. The grain was definitely smaller and round in shape resembling the *sirumani* type. These were suspected to be  $F_1$ 's, resulting from natural crossing with the *sirumani* variety which was growing next to the long type in the previous season, and were isolated and grown separately in the following season. The types had the characteristic shape of the *sirumani*, but the length of the spikelet was about intermediate between that of *sirumani* and *anaikomban*. The  $F_2$  segregation was rather complex in the case of vegetative characters like presence and absence of pigment on the glumes, palea, etc., but so far as the grain size and shape were concerned the segregation was sharp and definite. There were only two groups, the round *sirumani* type and the long *anaikomban* type. Table VII gives the ratios obtained of these two types in 6 families.

TABLE VII.

*Segregation of  $F_2$ 's of the natural crosses.*

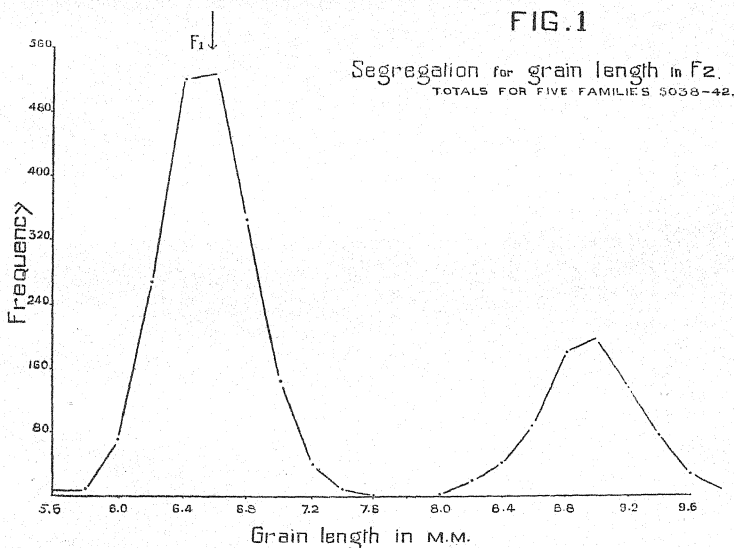
Family No.	SEGREGATING INTO		Ratio of round type to long type.
	Round type of grain	Long type of grain	
5038 . . . . .	386	143	2.7 : 1
5039 . . . . .	429	150	2.9 : 1
5040 . . . . .	379	140	2.7 : 1
5041 . . . . .	412	151	2.7 : 1
5042 . . . . .	363	160	2.3 : 1
5104 . . . . .	545	221	2.5 : 1
TOTALS . . . . .	2514	965	2.6 : 1
Cal. 3 : 1 . . . . .	2609	870	



1. Sirumani. 2. Anaikomban. 3. T. 24. (Parent in 6273). 4. T. 297. 5. T. 317 and E. B. 314.



The above segregation demonstrates a fair 3 : 1 ratio of round and short to long, though the deviation is 3.7 times the S.E. One typical panicle from each of the plants was harvested for the first 5 families and the actual length of the spikelets was measured, 6 grains to each panicle, and then averaged. It must be stated here that the dimensions of the grains, length, breadth, and thickness are always measured with a callipers provided with a vernier scale. Readings up to 0.1 mm. can be easily made and it has been found to be very satisfactory and reliable except in cases where the grains had any sort of bearding. Even in spikelet length there were two definite groups the first one varying from 5.6 mm. to 7.3 mm., and the second group from 7.9 mm. to 9.8 mm., with a clear break between the two. The segregation for these families is represented in Text-figure 1. All the grains with



the round shape were found to fall in the first group. The totals of the five families as per spikelet measurements are:—

	Round Shape	Long Shape
	1,924	752
Cal. 3 : 1 . . . . .	2,007	669

The deviation from the calculated 3:1 ratio is 3.7 times the S. E.

In one of the above families, 5038, a large number of selections were made with grain lengths covering the whole range of variation in  $F_2$ , and an  $F_3$  was raised.

Though the spikelet length of the long group varied from 8.2 mm. to 9.7 mm. all the selections, 16 in number made within this group, bred true to the long type. There were pure lines with varying mean spikelet lengths of 8.1 mm. to 9.1 mm. (Table VIII).

TABLE VIII.

*Spikelet lengths of  $F_2$  (5038) and the selections from it.*

Family No.	Spikelet length in mm. of parent	Behaviour of $F_2$	ROUND GRAIN			LONG GRAIN		
			Mean spikelet length in mm.	Standard deviation	Co-efficient of variation	Mean spikelet length	Standard deviation	Co-efficient of variation
$F_2$ 5038	..	..	6.6	0.28	4.3	8.9	0.32	3.6
$F_3$	5361	Pure round	6.0	0.17	2.9	..	..	..
	5362	"	6.3	0.20	3.2	..	..	..
	5363	"	6.2	0.16	2.7	..	..	..
	5375	"	6.0	0.16	2.7	..	..	..
	5376	Pure long	..	..	..	8.4	0.23	2.7
	5377	"	..	..	..	8.4	0.25	4.3
	5378	"	..	..	..	8.4	0.25	3.0
	5379	"	..	..	..	8.5	0.24	2.8
	5380	"	..	..	..	8.3	0.26	3.1
	5381	"	..	..	..	8.7	0.26	3.0
	5382	"	..	..	..	8.5	0.27	3.1
	5383	"	..	..	..	9.0	0.22	2.5
	5384	"	..	..	..	8.1	0.27	3.4
	5385	"	..	..	..	8.3	0.24	2.9
	5386	"	..	..	..	8.6	0.38	4.5
	5387	"	..	..	..	9.0	0.29	3.2
	5388	"	..	..	..	9.1	0.31	3.4
	5389	"	..	..	..	8.4	0.28	3.3
	5390	"	..	..	..	9.1	0.26	2.8
	5391	"	..	..	..	9.0	0.36	4.0
	5364	Round and long	6.2	0.16	2.4	8.4	0.25	2.9
	5365	"	6.3	0.24	3.8	8.6	0.27	3.2
	5366	"	6.4	0.22	3.4	8.8	0.33	3.8
	5367	"	6.3	0.16	2.6	8.6	0.34	4.0

Family No.	Spikelet length in mm. of parent	Behaviour of $F_2$	ROUND GRAIN			LONG GRAIN		
			Mean spikelet length in mm.	Standard deviation	Co-efficient of variation	Mean spikelet length	Standard deviation	Co-efficient of variation
5368	6.7	Round and long.	6.3	0.20	3.2	8.7	0.25	2.8
5369	7.0	"	6.6	0.20	3.0	8.9	0.27	3.0
5370	7.0	"	6.6	0.17	2.6	8.8	0.38	4.2
5371	7.0	"	6.5	0.18	2.8	9.0	0.23	2.6
5372	7.0	"	6.4	0.20	3.1	8.8	0.29	3.3
5373	6.8	"	6.4	0.21	3.3	8.7	0.29	3.3
5374	6.5	"	6.3	0.23	3.7	8.7	0.30	3.4

It should appear that the spikelet lengths below a certain minimum associated with the round shape of the grain breed pure for the size and shape, and all lengths above that minimum segregate throwing the long types. This minimum length appears to be somewhere about 6.2 mm. Of the 15 selections with the round shape of grain, 4 bred true and 11 segregated, instead of 5 and 10, which is a good enough fit, considering that the selections were rather few and made mainly from the consideration of the spikelet length. Although the  $F_2$  ratios were a little out of the normal 3 : 1 ratio, the  $F_3$  ratios are very much better and give a clear indication of the monohybrid nature of the character under study (Table IX).

TABLE IX.

*Segregation of  $F_3$ s of the natural cross.*

Family No.	SEGREGATING INTO		REMARKS
	Round type	Long type	
5364 . .	71	33	(Only two rows were planted for each family and hence the small numbers.) S. E. 14.5 Deviation = $320 - 285 = 35$ Dev. 35 S. E. 14.5 = $\frac{35}{2.4}$
5365 . .	78	25	
5366 . .	71	31	
5367 . .	83	19	
5368 . .	72	32	
5369 . .	79	25	
5370 . .	72	31	
5371 . .	76	28	
5372 . .	71	33	
5373 . .	60	35	
5374 . .	77	27	
TOTAL . .	819	320	
Cal. 3 : 1 . .	854	285	

Table VIII only gave an indication that the parental lengths of the pure breeding and the segregating round grained types were different but this is quite definite in the case of the large number of selections from another  $F_2$ , 5104. There were 48 selections, 44 with round type of grain and 4 with the long type. The four latter bred true to the long type, though with different mean spikelet lengths. Of the 44 round types, 14 bred true, while 30 were heterozygous, a very close ratio of 1:2. The mean parental spikelet length of the 14 pure breeding families is  $6.0 \pm 0.04$ , and that of the 30 splitting families  $6.24 \pm 0.03$ . The S. E. of comparing the two means is derived from the formula  $\varepsilon_{12} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$ . Evaluating, the S.E. is 0.014. The actual difference between the two means, 0.24, is  $(\frac{0.24}{0.014})$  17 times the S. E. and hence can be taken as very significant.

#### EVIDENCE FROM NATURAL HYBRIDS.

Since the establishment of the fact that the round short type and the long type behave as simple Mendelian allelomorphs, in the season 1924-25, some other natural crosses observed in the pure lines which were suspected to be hybrids between round and long types of grain were isolated and grown as  $F_2$ s. Table X gives the ratios obtained of these families.

TABLE X.

*Behaviour ( $F_2$ s) of natural crosses from pure lines.*

Family No.	Selection from	SEGREGATING INTO		
		round and short	round and medium long	long
6241 . . .	T. 263 . . .	53	126	68
6250 . . .	T. 3414 . . .	57	136	62
6255 . . .	E. B. 301 . . .	44	107	34
		523		164
6273 . . .	W. S. 374 . . .	302		105
TOTALS .	..	825		260
Cal. 3:1 .	..	821		274

By eye judgment three groups could be made out, one short and round, a second round but rather long, and a third non-round but long. Though the separation according to the length of the spikelets may not be quite accurate, the distinction between round and non-round was very definite.

In the case of the family No. 6273, the difference in the spikelet lengths between the two parents involved in the cross (Plate I, 1 & 3) is under 1.5 mm. and the classification of the  $F_2$ s by the length of the spikelet would have been impossible. It is the segregation for the shape, round and long, that made the classification quite simple. The behaviour of the other three families would seem to indicate a more or less 1:2:1 ratio as regards spikelet length.

#### CONFIRMATORY EVIDENCE FROM CROSSES SPECIALLY MADE.

To confirm the results obtained from the study of natural crosses, two definite artificial crosses were made at the Coimbatore Paddy Breeding Station in the season 1924-25. T. 297 (Plate 1, 4) was the round grained parent in both the crosses, and the grain shapes and lengths of T. 317 and E. B. 314 (Plate 1, 5) were exactly similar being very thin and long. The parents selected for the crosses had spikelet shapes corresponding to types (iii) and (v) of Graham's classification. The results of the cross are summarized in Table XI and the grain measurements of the  $F_2$ s represented in Figure 2.

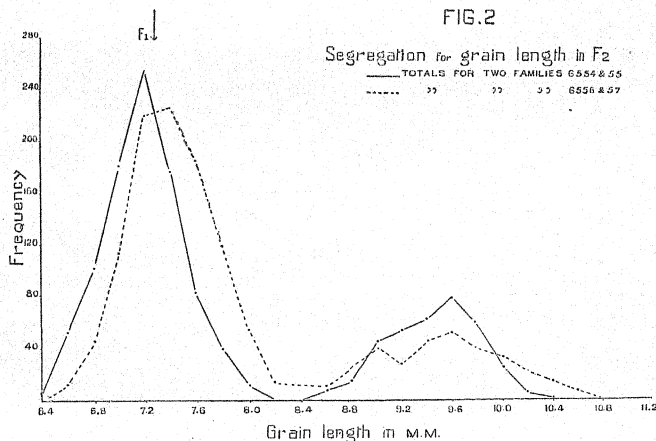


TABLE XI.

*F<sub>1</sub>s and F<sub>2</sub>s of crosses T. 297 × T. 317 and T. 297 × E. B. 314.*

Parents	ROUND TYPE OF GRAIN				LONG TYPE OF GRAIN			
	Range of variation in spikelet length mm.	Mean spikelet length mm.	Standard deviation	Co-efficient of variation	Range of variation in spikelet length mm.	Mean spikelet length mm.	Standard deviation	Co-efficient of variation
Cross I. T. 297 (round grain).	5.3-6.3	5.81	0.23	3.92	..	..	..	..
T. 317 (long grain)	..	..	..	..	9.7-11.7	10.79	0.45	4.12
F <sub>1</sub> 6316 . .	6.4-7.8	7.25	0.24	3.26	..	..	..	..
F <sub>2</sub> 6554 . .	6.4-8.4	7.40	0.34	4.65	8.6-11.0	9.81	0.45	4.50
6555 . .	6.6-8.2	7.31	0.31	4.02	8.7-10.6	9.73	0.37	3.75
Cross II. T. 297 (round grain.)	5.0-6.3	5.71	0.27	4.69	..	..	..	..
E. B. 314 (long grain).	..	..	..	..	9.6-11.6	10.55	0.41	4.15
F <sub>1</sub> 6317 . .	6.3-7.5	7.06	0.23	3.30	..	..	..	..
F <sub>2</sub> 6556 . .	6.4-8.0	7.19	0.32	4.45	8.6-10.9	9.47	0.42	4.43
6557 . .	6.4-8.0	7.08	0.28	3.95	8.6-10.0	9.36	0.33	3.53

*Simple counts of round and long grains in F<sub>2</sub>s.*

Family	Round	Long	Deviation	Devn. S. E.
6554 . . . . .	520	176		
6555 . . . . .	477	160		
6556 . . . . .	422	167		
6557 . . . . .	503	183		
TOTAL . . . . .	1922	686		
Cal. 3:1 . . . . .	1956	652	34	1.5

The parents chosen are probably two extremes regarding grain size and shape in rice. Both of them were obtained from the collection of pure lines that have been growing on the station for some years. So far as the grain shape was concerned, all the F<sub>1</sub>s were rather roundish than long. As regards grain lengths, they were intermediate, though not quite so, the mean being about 13 per cent. less than the theoretical mean of the two parents. The lower limit of the F<sub>1</sub>s is about the maximum limit of the small grained parent. The F<sub>2</sub>s were grown in 1926-27. The range of variation in F<sub>2</sub>s is rather interesting. Taking the ranges of variation and the mean lengths of the two groups separately, the lower limit of the short grain group never goes below the maximum range of the short grained parent, and the mean of this group is about the same as that of the F<sub>1</sub>. When the range of variation in the long grained group is examined, although the maximum limit of the

long parent is touched, the mean length is definitely below that of the long parent. It follows, therefore, that any selection with the long type of grain from the  $F_2$ s should have a smaller mean spikelet length than the long parent that went into the cross. In the same way any selection from  $F_2$ s breeding pure for the short type of grain should have a mean spikelet length greater than that of the small grained parent. This has been well established in the case of the extracted types of the first natural cross, *sirumani*  $\times$  *anaicomban*, that have been grown on the station for some years now. It has been the experience here as elsewhere that the parental types extracted from any cross are rarely the same as the parents that went into the cross, at least so far as quantitative measureable characteristics are concerned. This has been explained as 'Shift' by Engledow<sup>1</sup> in his *T. polonicum*, *T. durum* cross. The fairly high co-efficient of variability observed in the long grained group possibly suggests the presence of minor subsidiary factors besides the main one that determines the length of the spikelet. The possibility of getting pure breeding types with various intermediate spikelet lengths reaching up to the maximum of the long parent adds further evidence as to the existence of such minor factors.

#### ASSOCIATION OF GRAIN SIZE AND SHAPE.

In all the cases herein discussed, except that of family 6273, mentioned in Table IX, the short spikelet and the long spikelet have been found to behave as a simple pair of allelomorphs. The short spikelet length has been, in all the cases mentioned, associated with a round shape of grain which is dominant to the other shape. It is this association that has made the  $F_2$  classification easy and feasible. The one case, that of family 6273, mentioned above, where the difference in the grain lengths of the parents involved is hardly enough to allow classification of  $F_2$ s by spikelet length has definitely proved the simple dominance of the round shape to the ordinary long shape. Lien Fang Chao<sup>2</sup> has published results that the short spikelet is a simple dominant to the long one. From the figures given by him in the text, it is clear that the parent with the short spikelet he has used in the cross has also round grains similar to the cases discussed here. Van Der Stok<sup>3</sup> has studied the inheritance of this character, and he mentions that the segregation is irregular, and that the small round fruits which he calls *R. R. minuta* and the larger or medium rice which he calls *R. R. communis*, are equal in value. There are reasons to believe that the spikelet length apart from the round shape is not such a simple character as should be expected from the foregoing results. In the case of a cross made on the station for a different purpose, where the round shape did not come in, the difference between the parental spikelet lengths was sufficiently big to allow classification of the  $F_2$ s by measurements. The mean spikelet

<sup>1</sup> Engledow, F. L. (1920 and 1923). The inheritance of glume length and grain length in a wheat cross. *Jour. of Genetics*, Vols. X and XIII.

<sup>2</sup> Lien Fang Chao (1923). Linkage studies in rice. *Genetics*, Vol. XIII, No. 2.

<sup>3</sup> Van Der Stok, J. F. *Die Zuchtung der landwirtschaftlichen kulturpflanzen*, c. Fruwirth, Vol. 5.

length of one parent was about 8 mm. and that of the other about 5.5 mm. The  $F_1$  was more or less intermediate and in the  $F_2$  we got a variation from 5.3 mm. to 9.0 mm. There was no indication of any break in the range and there were types in  $F_2$  exceeding the parental limits in either direction. It is found that almost all the pure lines which we have in our general collections having the round shape of grain are also very short in spikelet lengths. There are a few exceptions where the spikelet length is very short, even shorter than the round types, but the grains are not at all round, and it is on such types further work is in progress to throw definite light on the inheritance of spikelet length. We have not got a single type in our collections where the spikelet is round and at the same time long. The results obtained from the foregoing study would lead us to assume that beyond a certain limit in spikelet length the grain cannot have a round shape.

#### SUMMARY.

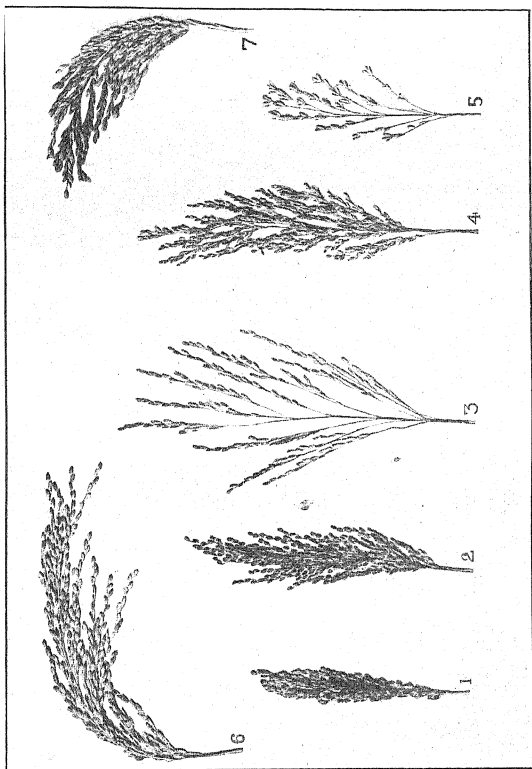
The rices can be classified according to the shape of the fertile glume and palea. Two important groups according to this classification are, (i) the round short grains where the lemma and the palea are convex, and (ii) the ordinary coarse long type where the glume and palea are slightly convex. The former is a simple dominant to the latter. The factor or factors responsible for the spikelet lengths are different from that deciding the shape, but the two may be associated, in which case the short spikelet length behaves as a simple dominant to the long spikelet length. It is this association of the spikelet length with the round shape of the grain that makes the  $F_2$  classification simple. Segregation may occur either for the shape only or for the spikelet length only. Though the former is simple, there is evidence to believe that the latter is more complicated.

The extracted parental types are never the same as those that went into the cross, there being an increase in the spikelet length of the short parent, and a reduction in the long parent. This phenomenon, termed 'Shift' by Engledow, is very definite, and there are indications to believe that there are a number of minor subsidiary factors influencing spikelet length besides the main one. The obtaining of several pure breeding types with different mean spikelet lengths lends strength to this possibility.

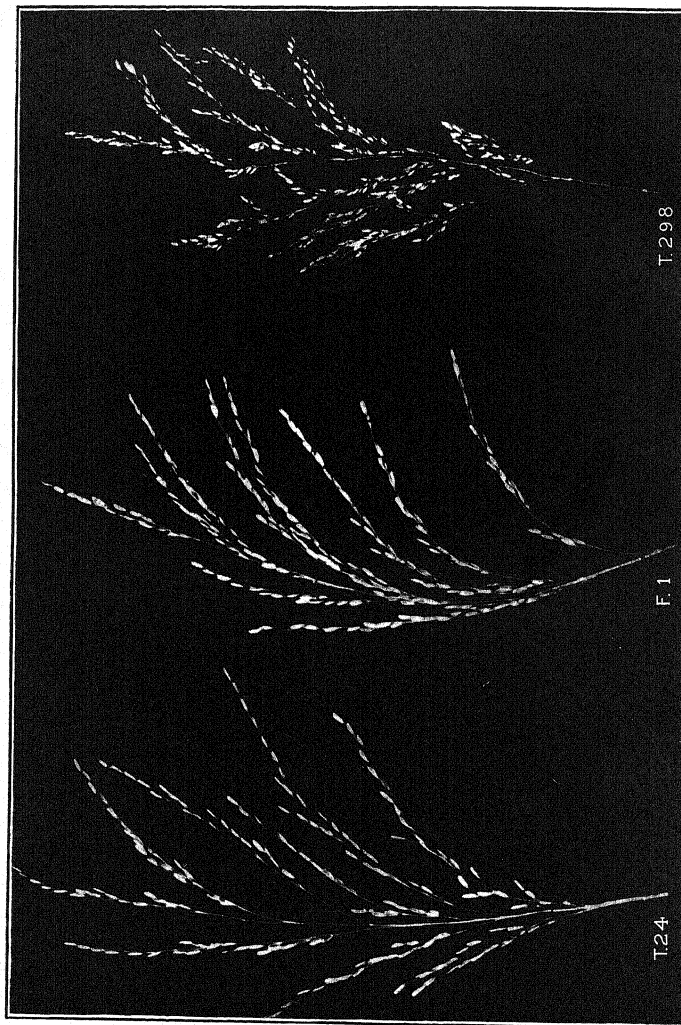
### III. Inheritance of lax and dense panicles in rice.

#### INTRODUCTION.

Density in the panicle is the combined result of a number of factors like the length of the panicle, the total number of spikelets in the panicle, the number of branches borne on the main axis, and the length of the flower bearing part of the individual branch. The density of the panicle varies greatly in the different varieties of cultivated rice. Plate II represents some of the important types met with in the Coimbatore collections. The central type 3 in the plate is the very loose



1. E. B. 304. 2. T. 297. 3. T. 24. 4. T. 298. 5. E. B. 331. 6. E. B. 301. 7. E. B. 197.



open one characteristic of the strain No. 24 evolved at the station. At the other extreme we have the dwarf rice (Plate II, 1) which has a characteristic dense panicle resembling that of *Pennisetum typhoides*. The variety T. 298 (Plate II, 4), one of the finest rices, has a panicle which though not so compact as the dwarf rice, exhibits a fairly dense grain arrangement. For the same length of the panicle we get the largest number of grains. Bhide<sup>1</sup> has found that sparseness of grain arrangement is dominant to compactness, and that compactness is generally associated with short grains.

#### SOURCE OF MATERIAL AND PROCEDURE OF WORK.

To study the inheritance of this character and to find out if the denseness associated with the variety T. 298 could be introduced in the strain No. 24, a cross was made between these two types in the year 1920-21. The panicle of the  $F_1$  showed the complete dominance of the lax 24 type, with little suggestion of the denseness characteristic of the other parent (Plate III). The size of the grain was intermediate. Two  $F_2$  families were raised in 1922-23, and they exhibited a simple segregation of the lax and dense types of panicle (Table XII).

TABLE XII.  
 $F_2$  of Lax  $\times$  Dense panicle.

Family No.	Lax panicle	Dense panicle	Dev.	Devn. S. E.
3978 . . . .	1,483	462		
3979 . . . .	1,225	352		
TOTAL . . . .	2,708	814		
Cal. 3 : 1 . . . .	2,611.5	880.5	65.5	2.6

One typical panicle per plant was collected in each of these families and the classification into lax and dense panicles was done very carefully in the laboratory. Besides the two typical lax and dense types, two more intermediate groups were introduced consisting of all the doubtful ones, as shown below.

Family No.	Lax typical 1	Lax doubtful 2	Dense doubtful 3	Dense typical 4
3978 . . . .	1,335	102	62	423
3979 . . . .	1,075	83	48	306

It was decided to raise an  $F_3$  and make use of the experience to reclassify the  $F_2$  once again. Four rows of plants were taken individually in family No. 3979 which

<sup>1</sup> Bhide, R. K. (1925). Proceedings of the meeting of the Botanical Society of Poona. Published in the *Jour. Indian Bot.*, Vol. V, No. 1.

gave 65, 8, 2, and 23 plants respectively of the four groups. About 100 plants were grown from each of the above selections and their behaviour was as follows.

*No. taken.*

Typical lax types . . . . .	65 . . . . .	27 bred pure for lax. 38 gave lax and dense types.
Doubtful lax . . . . .	8 . . . . .	1 bred pure lax. 5 gave lax and dense types.
Doubtful dense . . . . .	2 . . . . .	2 bred pure for dense type.
Typical dense . . . . .	23 . . . . .	2 bred pure for dense. 23 bred pure for dense type.

Taking away 25 per cent. of the doubtful lax types into the dense group as a result of the  $F_3$  behaviour, and reclassifying the  $F_2$  we get :

	Lax	Dense
Cal. 3 : 1 . . . . .	1,137	375
	1,734	378

The above figures clearly demonstrate a simple 3 : 1 Mendelian ratio. Out of the 71 selections, 28 bred pure for the lax panicle, and 43 segregated instead of 24 and 47 which is not very much out of the 1 : 2 ratio. The 43 segregating families gave a total of 2,569 lax, and 695 dense types, which is not at all a good 3 : 1 ratio. This may be due partly to the small percentage of plants that were grown in each family, and partly to the difficulty of the classification by the presence of the doubtful ones. Taking away 3 per cent. of the lax group into the dense group as was done in the case of the  $F_2$ , we get 2,492 lax, and 772 dense, which is a good enough 3 : 1 ratio, the deviation divided by the standard error being only 1.8. Since the obtaining of the above results a few natural crosses observed in the pure lines with somewhat dense panicle types, were isolated and grown separately in 1924-25 to get additional information about the inheritance of this character. The results of the  $F_2$  counts are given in Table XIII below.

TABLE XIII.  
 *$F_2$ s of natural crosses.*

Family No.	Lax type	Doubtful lax type	Typical dense type	Deviation	Devn. S. E.
6240 . . .	199	32	53		
6244 . . .	128	54	66		
6243 . . .	5	173	67		
6261 . . .	117	75	50		
6262 . . .	134	50	55		
TOTALS .	584	384	300		
	968				
Cal. 3 : 1 .	961		317	17	1.1

Though the typically dense type was easily distinguishable, and forms a definite group in the above classification a doubtful group has been introduced as there was found to be variation in the lax types of the different families. Unlike the progenies of the cross T. 298  $\times$  T. 24 dealt with earlier, the lax parents involved in the above crosses could not all have been of the same genetic constitution, and in addition none of these was as lax as the type 24 which is an extreme example for this character. There is also another difficulty introduced in the classification due to the difference in the size of the grains which is found to influence somewhat the arrangement of the grains in the panicle. There was, however, no indication in any of the families, that the dense type of panicle could be a partially dominant character giving an intermediate form of  $F_1$ .

#### ECONOMIC POSSIBILITY OF THE CROSS.

None of the selections in the original cross T. 298  $\times$  T. 24 could be thought of as economically useful as it was noted in the  $F_1$  that a large amount of spikelet sterility (failure to produce grain) had been brought in, in spite of the fact that it was not present to any extent in the parents. This sterility continued to persist in various degrees in the later generations. It has been mentioned already, that as regards the size of the grains, the  $F_1$  was intermediate between the two parents. In the two  $F_2$ s, six spikelets were measured for each panicle and the averages were tabulated along with the type of the panicle in which they occurred. The mean spikelet lengths for the two types of panicles were, lax  $7.57 \pm 0.02$ , and dense,  $6.88 \pm 0.03$ .

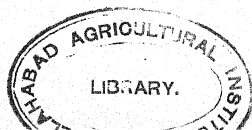
TABLE XIV.

*Tabulation of spikelet length and density of panicle in  $F_2$ .*

Spikelet length in mm.	6.2 and less	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0 and above	Total
Lax panicle	20	30	86	86	154	179	163	135	95	482	1,426
Dense panicle	105	61	40	28	35	61	62	36	23	25	485
TOTAL	125	91	135	114	189	240	225	171	118	507	1,921
	159	586	608	197	499	241	248	111	144	772	304
	x	x	x	x	x	x	x	x	x	x	x
	$10^4$	$10^4$	$10^4$	$10^4$	$10^3$	$10^4$	$10^4$	$10^4$	$10^4$	$10^4$	10

Applying the test of independence<sup>1</sup> Table XIV gives  $X^2=437$ . For  $n=9$ , and  $X^2=437$ , the value of P is .00000— . It is therefore evident that the two

<sup>1</sup> Fisher, R. A. Statistical methods for research workers, p. 85.



samples are independent and that there is a partial association of the two characters, spikelet length and the density of the panicle, smaller grain with a dense arrangement of the grain, and the longer grain with a lax arrangement. In this connection it is worth mentioning that from a rough examination of the pure lines, it is seen, that a dense type of panicle is invariably associated with small or medium spikelets and never with the long ones, thus confirming Bhide's observations.

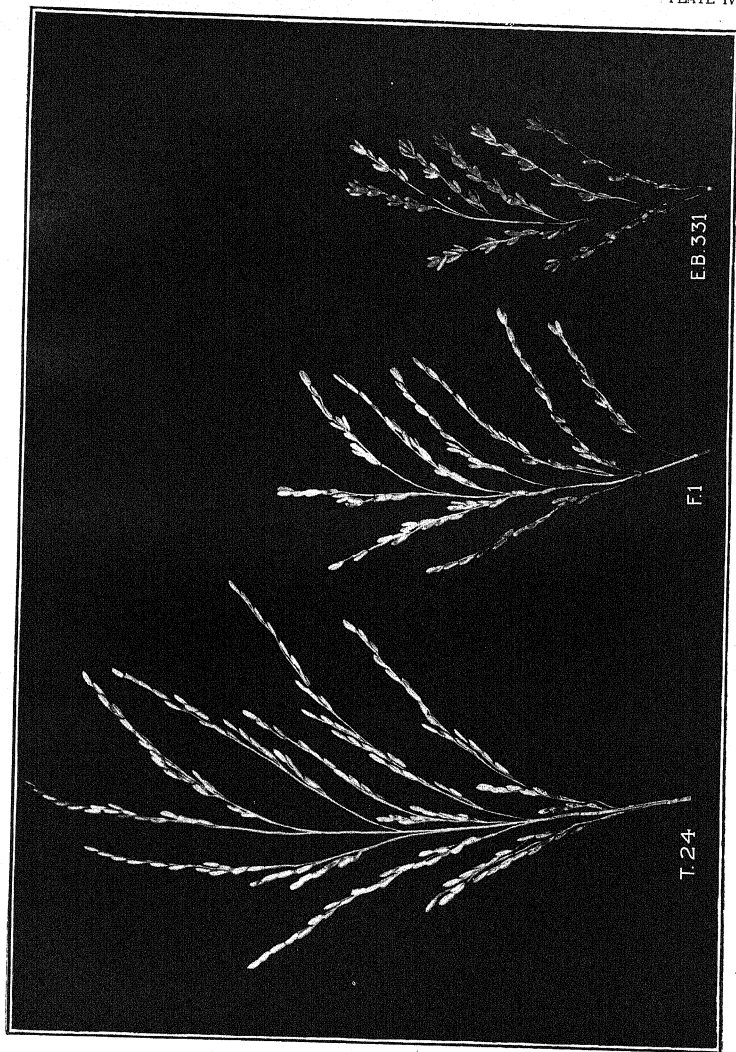
#### IV. Inheritance of clustering in rice spikelets.

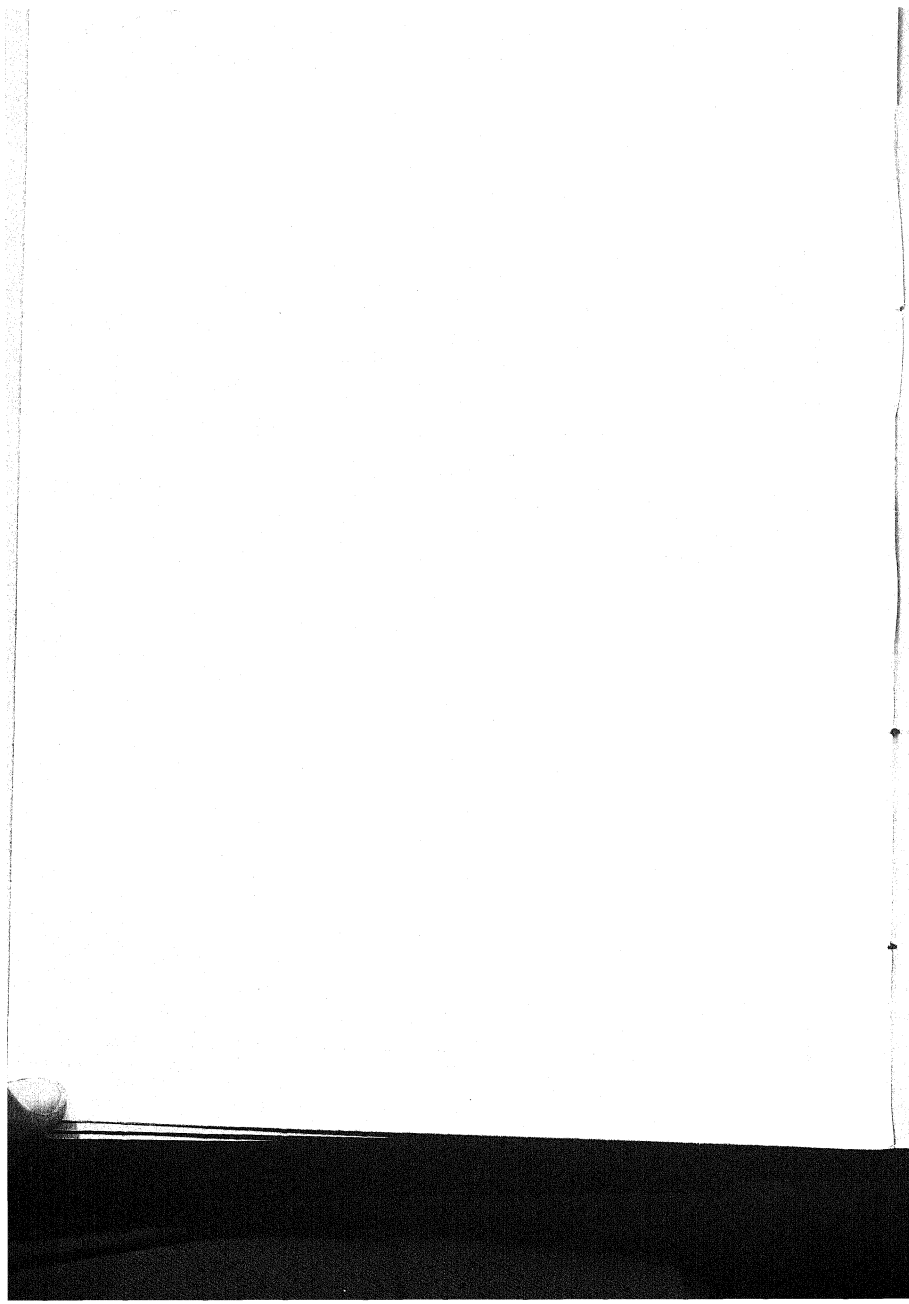
Although the spikelets of the rice panicle are usually solitary, in one variety obtained by the courtesy of the Bombay Agricultural Department, it is found that the spikelets are clustered on the secondary branches, and at the tips of the main branches, 2 to 5 occurring close together (Plate II, 5). The branches of the panicle have a slightly interrupted appearance, and probably to compensate for this character the total length of the panicle is rather reduced. To study the inheritance of this clustering character, and if possible to combine it with a greater length in the panicle a cross was made between this variety and T. 24 in the year 1920-21. Plate IV shows the two parents with the  $F_1$  in the middle. The  $F_1$  panicle is very much like that of T. 24, with this difference, that at the tips of the main and secondary branches of the panicle, the spikelets appear in twos. The  $F_1$  can therefore be said to be intermediate between the two parents. The  $F_2$ , as was to be expected, gave three groups of plants, two like the two parents, and the third like the intermediate  $F_1$ . In the actual classification of the  $F_2$ s, besides the three groups, two additional groups were introduced consisting of all the doubtful ones. Table XV gives the ratios obtained for two families.

TABLE XV.

$F_2$  of T. 24  $\times$  E. B. 331, Cluster paddy.

Family No.	Typical cluster	Doubtful cluster	Doubtful $F_1$ s	Typical $F_1$ s	Typical 24
	1	2	3	4	5
3968 . . .	18	42	7	523	300
3969 . . .	253	..	99	386	252
TOTALS .	436	42	173	909	552
	478		1,082		552
Cal. 1 : 2 : 1 .	528		1,056		528





Whatever would not obviously go into either group 1 or 4, were left in groups 2 and 3. The ratios in all probability represent a 1:2:1 ratio, the  $F_1$  being intermediate between the two parents. It was decided to grow an  $F_3$  and reclassify the  $F_2$  from the experience gained. Four rows of plants were harvested in family No. 3968 which gave 18, 4, 6, 46, and 26, plants respectively of the 5 groups. To be absolutely sure of the behaviour of plants in groups 2 and 3, 5 extra selections were made in each of these. The behaviour of these selections is summarized in Table XVI below.

TABLE XVI.

*Behaviour of  $F_3$ s of  $T. 24 \times E. B. 331$ , Cluster paddy.*

Group number	Character of the group	Number of selections made	Behaviour of $F_3$
1	Typical cluster . . .	18	All pure clustering.
2	Doubtful cluster . . .	9	8 pure clustering, 1 segregating like $F_1$ .
3	Doubtful $F_1$ types . . .	11	3 pure clustering 8 segregating like $F_1$ .
4	Typical $F_1$ types . . .	46	All segregating like $F_1$ .
5	Typical 24 type . . .	26	All pure for the absence of clustering as in T. 24.

In the light of the above behaviour of the  $F_3$ s, the  $F_2$ , 3968, is reclassified we get :

	Cluster	Intermediate	Non-cluster
	241	581	300
Cal. 1:2:1 .	280.5	561	280.5

which is a very much better 1:2:1 ratio than was obtained previously. The 55 segregating  $F_3$  families gave a total of :

	Cluster	Intermediate	Non-cluster
	1,115	2,088	1,070
Cal. 1:2:1 .	1,068	2,136	1,068

which is a good enough approximation to the theoretical figures. Then again of the 110 selections, 29 families have bred pure for the clustering character, 55 families have segregated giving all the three types, and 26 families have bred pure for the non-clustering character which is a good 1:2:1 ratio. It is, therefore, quite definite that the clustering and the non-clustering character of the spikelets on the panicle behave as a simple pair of Mendelian allelomorphs.

## HEIGHT AND DURATION.

The details about the inheritance of these two characters will appear later when the results are to be written up. It is enough to mention here that the two parents were found to vary slightly for duration and height, the 24 parent being about half a foot taller and about 10 days later than the cluster paddy. The  $F_1$  was intermediate for the characters. There was apparently no segregation in the  $F_2$  but some of the  $F_3$  and  $F_4$  selections gave a sharp segregation and gave a good 3:1 ratio of early short to late tall, the difference in height and duration between the two groups being about 6 to 8 inches and a week to 10 days respectively. No connection was, however, observed between these characters and the grain arrangement in the panicle.

## V. Inheritance of dense arrangement and clustering of spikelets in rice panicles.

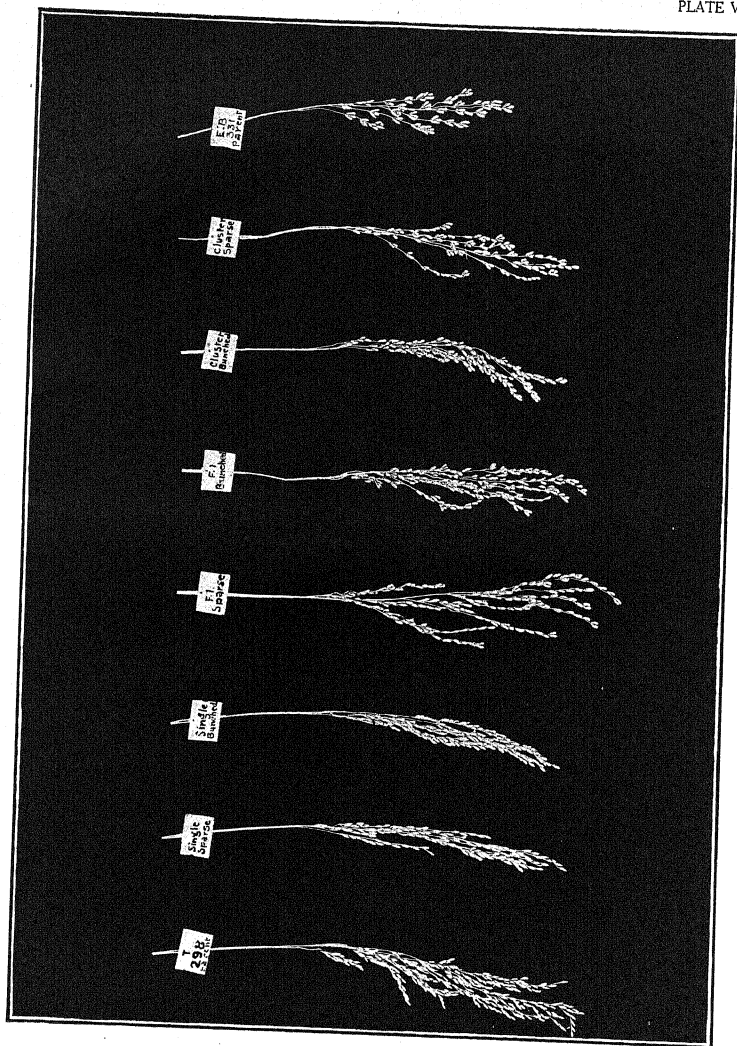
In section III, it was shown from a cross between T. 24 and T. 298 that the lax panicle was a simple dominant to the dense panicle. In section IV, it was shown from a cross between T. 24 and Cluster paddy that clustering was a partial dominant to the ordinary panicle. A cross was now made between T. 298 having a dense panicle and Cluster paddy. As was to be expected from the results of the previous crosses, the  $F_1$  was lax for the grain arrangement and was intermediate for the clustering character. The  $F_2$ s were grown in 1924-25, and when the panicles were classified, it was found there were six different groups as shown in Table XVII. The ratios conform to a di-hybrid ratio. The parents and the  $F_2$  types are represented in Plate V.

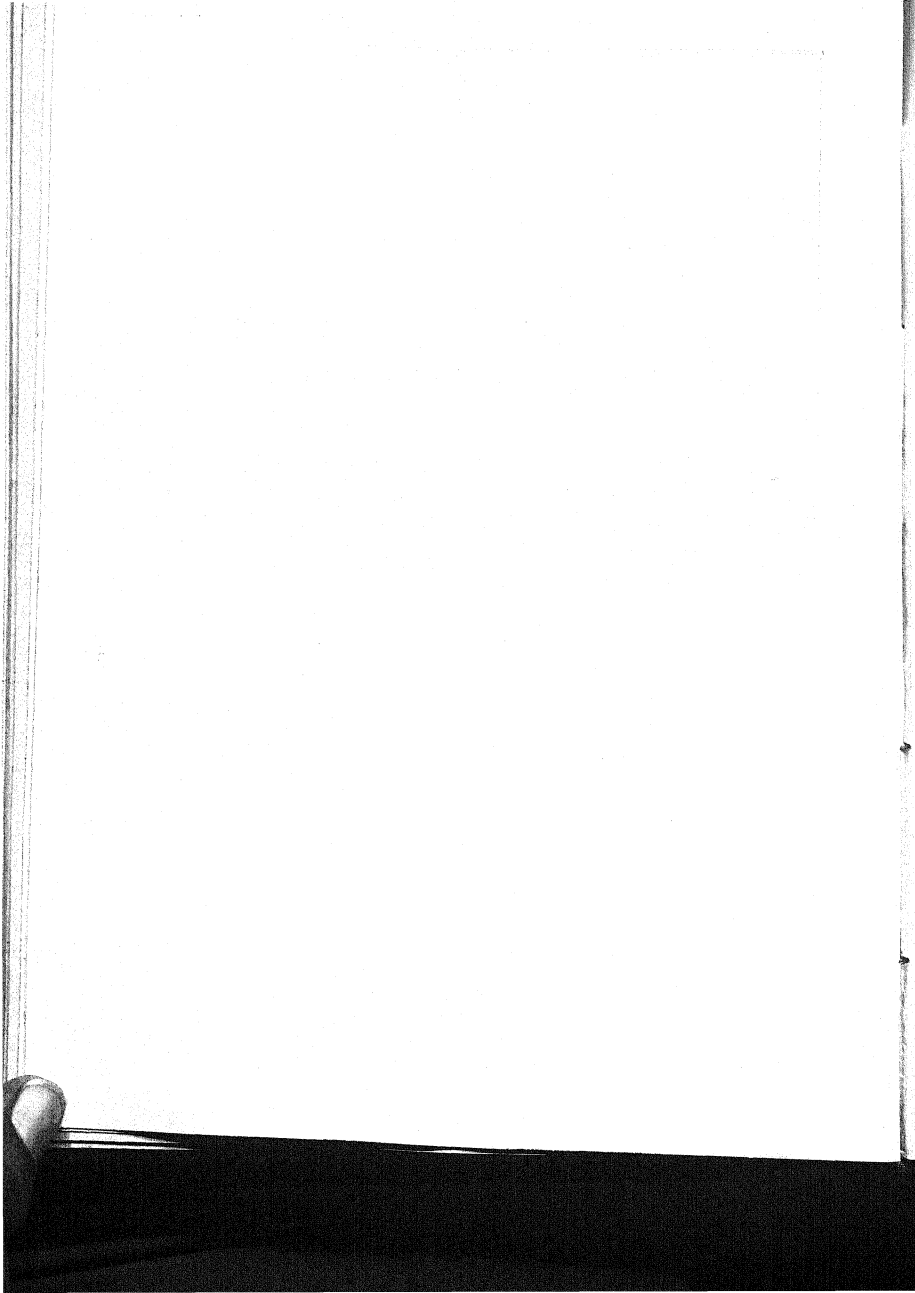
TABLE XVII.

$F_2$ s of T. 298, dense panicle  $\times$  E. B. 331, Cluster paddy.

Family No.	Typical cluster lax panicle	Intermediate cluster lax panicle	No cluster lax panicle	Cluster and dense panicle	Intermediate cluster and dense panicle	No cluster but dense panicle
	SSCC or SsCC	SSCc or SsCc	SScc or Sscc	ssCC	ssCc	sscc
6202 . . .	147	321	148	50	108	70
6203 . . .	167	328	135	44	93	70
6204 . . .	123	241	138	40	89	43
6205 . . .	138	266	116	35	68	56
6206 . . .	163	324	135	29	61	47
6207 . . .	142	272	158	22	94	80
6208 . . .	174	360	200	51	106	93
6209 . . .	110	323	153	27	87	55
TOTAL .	1,173	2,435	1,183	208	706	520
Cal. 8:6:3:1:2:1	1,185	2,370	1,185	395	790	395

Parents and F<sub>2</sub> types of T. 298 × E. B. 331.





Taking factors S and C to represent the lax type of panicle and the clustered arrangement of the grain on the panicle respectively, the Cluster paddy will have the formula S S C C, and T. 298 s s c c. The F<sub>1</sub> of the cross will be S s C c. There should occur six phenotypes in F<sub>2</sub> as shown below in the ratios marked against each type.

[illegible]

The actual ratios of Table XVI do not agree well with the above expectations, but the types are represented. The last three groups of the table are particularly out of line although their totals to the rest form a close 1 : 3 ratio. When the two characters, clustering of spikelets, and the denseness of the spikelets, occur together the separation of the sub-groups was found to be extremely difficult, and this accounts for the wide deviations of the actual ratios from the expected. The ratios for the two characters taken separately, however, agree fairly with the expectations.

LENGTH OF PANICLE.

There was a difference of nearly 8 cm. in the average lengths of the panicles between the two parents, the mean length of T. 298 being 24.9 cm., and that of E. B. 331, 17.0 cm. The  $F_1$  was intermediate, more approaching that of T. 298 while the  $F_2$  gave a continuous range of variation from 15 to 28 cm. suggesting that the character is controlled by multiple factors. There was no definite connection between the length of the panicle and the grain arrangement although there was a slight indication that the typical clustered panicles were rather shorter in length than those without clusters.

### EMERGENCE OF THE PANICLE.

By emergence is here meant that portion of the panicle stalk between its bottom-most node and the leaf junction of the top-most leaf. The parents did not materially differ for this character, it being about 14 cm. for both. The  $F_2$  however, gave a wide range of transgressive variation from 4 to 22 cm. indicating that the character is controlled by multiple factors. There was no apparent connection between this character and the grain arrangement in the panicle.

## DURATION.

There was a difference of about a week to 10 days in duration between the two parents. The  $F_1$  was intermediate and the  $F_2$  was also intermediate, the variation being well within the range of the two parents. There was no sharp segregation for the character even in  $F_3$ s and  $F_4$ s as was obtained in the cross T. 24  $\times$  E. B. 331, mentioned in Section III although pure breeding extracted types differed slightly in duration from each other. No relation was observed between this character and grain arrangement.

## STERILITY.

As was mentioned in the case of the cross T. 24  $\times$  E. B. 331, there was a large amount of spikelet sterility appearing in the progenies of this cross, precluding all possibilities of evolving types economically useful. There was a definite association between sterility and panicle emergence, the plants with a poor emergence exhibiting a larger amount of sterility as compared with those with good emergence. There was also some connection between sterility and the panicle type, the dense-type having comparatively a larger percentage of unset spikelets than the lax type.

## VI. Inheritance of 'mottling' over fertile glumes in rice.

In certain families derived from natural crosses splitting for some type of gold or dark furrow colouring over the fertile glumes, there appeared a number of plants with mottled grains. The mottling is not seen until the grain is perfectly ripe, irregular light coloured areas then appear scattered over the grain and give it a distinctly moth-eaten appearance. Mention has already been made of this character.<sup>1</sup> The results given then appeared to show the mottled type to be simply recessive to even colouring.

To confirm the results obtained then, a definite cross was made in 1923-24, between T. 3608 and P. S. 32, pure types for mottled dirty and even dirty respectively. The  $F_1$  was grown in 1924-25. The grains when they were ripe, instead of remaining even coloured, as should be expected from the results already published, exhibited, small light coloured patches—a reduced form of mottling as is seen in Plate VI. All the  $F_1$ s grown showed the slight mottling but none to the same extent as the parent T. 3608, indicating the mottling to be a partially dominant character.

Four  $F_2$ s were grown in 1925-26, and in all the families there was segregation to various degrees of mottling besides the plants with definitely even colouring. In the classification, the definitely mottled type approaching the parental form was kept separate, and the rest of the mottled types grouped together. The ratios obtained are given in Table XVIII.

<sup>1</sup> Parnell, F. R., and others. Inheritance of characters in rice, I. *Mem. Dept. Agri. India, Bot. Series*, Vol. IX, No. 2.



T. 3808  
mottled



F1



P. S. 32  
ordinary

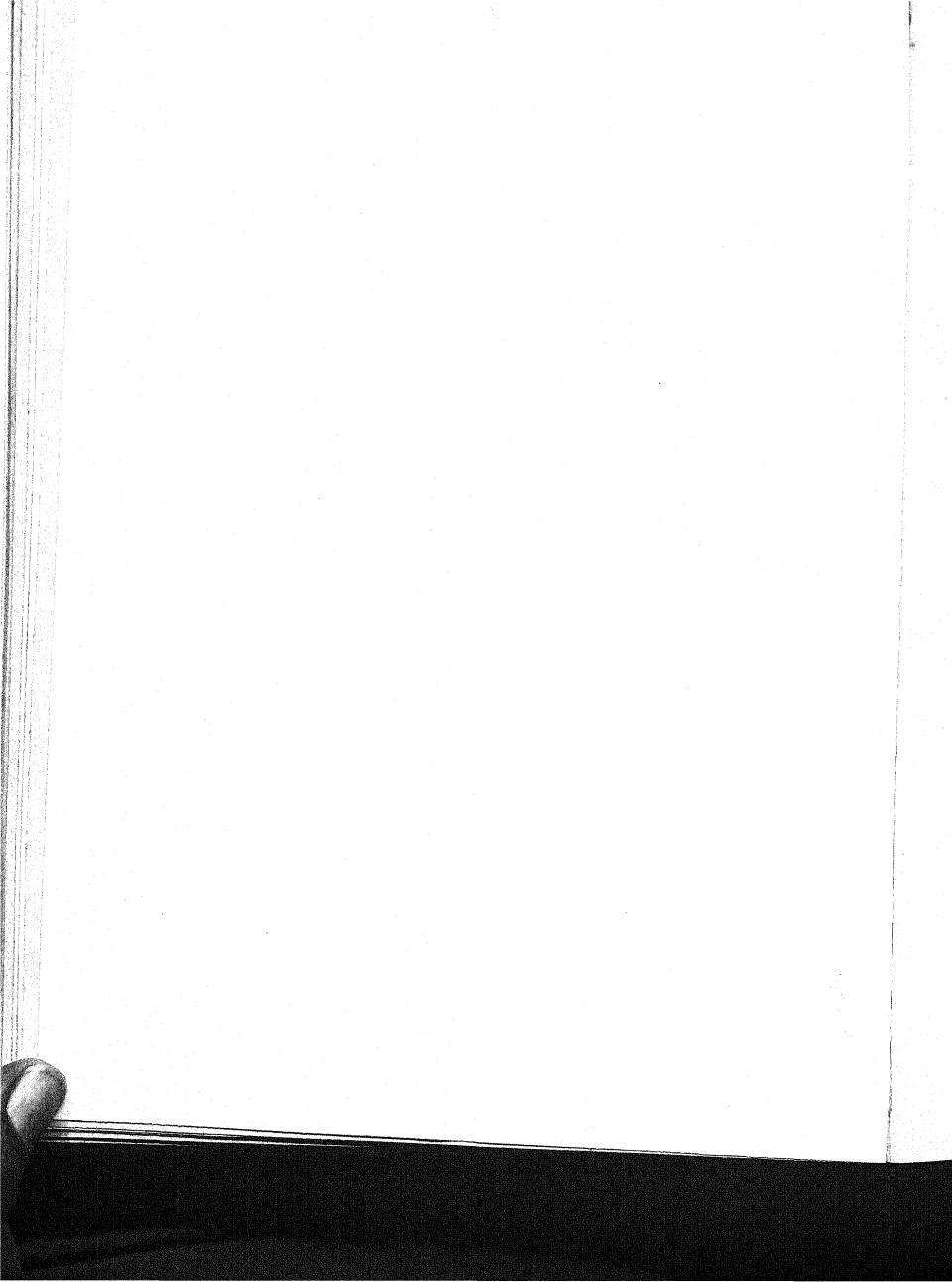


TABLE XVIII.

 $F_2$  of mottled dirty  $\times$  even dirty.

Family No.	Mottled dirty	Intermediate mottled dirty	Even dirty
6221 . . . .	178	420	201
6222 . . . .	215	376	198
6223 . . . .	186	434	197
6224 . . . .	185	434	220
TOTAL .	764	1,664	816
Cal. 1 : 2 : 1 .	811	1,622	811

In the case of family No. 6222, the classification of the groups was made in the fields, while in the case of the other three, typical panicles one from each plant were collected and examined later in the laboratory.

To confirm the results of  $F_2$ , 20 selections were made in one of the above families, and grown as  $F_{3s}$ . Their behaviour, as is shown below, entirely confirmed the  $F_2$  results.

Family No.	$F_2$ character	$F_3$ behaviour
(6447-50) 4	Mottled dirty . . . .	Pure mottled dirty.
(6451-54) 4	Even dirty . . . .	Pure even dirty.
(6455-66) 12	Intermediate mottled dirty . .	Splitting giving all three types.

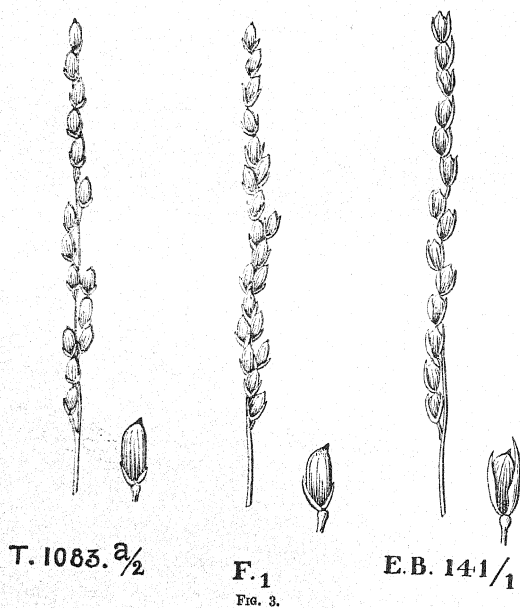
The above results show that the *even dirty* and the *mottled dirty* behave as a simple pair of Mendelian allelomorphs, the  $F_1$  being intermediate for the mottled character.

#### VII. Inheritance of the size of the outer glumes in rice.

The inheritance of the size of outer glumes had been studied before,<sup>1</sup> and the character was then shown to be a simple Mendelian recessive. Like the variety

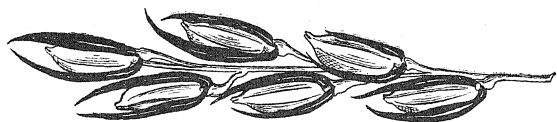
<sup>1</sup> Parnell, F. R., and others. Inheritance of characters in rice, I. *Mém. Dept. Agri. India, Bot. Series*, Vol. IX, No. 2.

T. 290 (Rakkipakshibhatta) mentioned in that study, there are other varieties also which have such long outer glumes. One such is E. B. 141, where the outer glumes are even longer than in T. 290 studied before. To find out whether this character was genetically the same in the two varieties, a cross was made between E. B. 141 and T. 1083, a variety with ordinary outer glumes. The  $F_1$  instead of having outer glumes like T. 1083, as should be expected from the previous results, had outer glumes intermediate in size as is shown in Fig. 3. This led us to believe that the character of the outer glumes in E. B. 141 was a partial dominant and the behaviour of two  $F_2$  families grown in 1925-26 (Table XIX) confirmed our expectations.

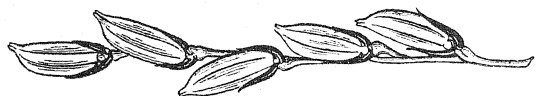




F<sub>2</sub> OF T.1083 X E.B. 14-1



209



584



227

TABLE XIX.

 $F_2$  of *E. B. 141*  $\times$  *T. 1083*.

Family No.	Ordinary outer glume	Intermediate type	Long outer glume
6193 . . . . .	258	481	244
6199 . . . . .	178	327	168
TOTALS . . . . .	436	808	412
Cal. 1 : 2 : 1 . . . . .	414	828	414

Plants with the long outer glumes are almost one-fourth of the total, and the slight preponderance of plants with the ordinary outer glumes may be due to the difficulty experienced in the separation of some of them from the intermediates. Plate VII gives an idea of the range of variation obtained in the size of the outer glumes, all the middle five classes grouped together as intermediates.

12 plants representing all the variations in the intermediate group, were selected from family No. 6199, and grown as  $F_3$ s. All the selections segregated for the size of outer glume, and gave the three groups as in  $F_2$ . The total ratios for the 12 families were :—

	Ordly. outer glume	Inter. type	Long outer glume
	227	584	209
Cal. 1 : 2 : 1 . . . . .	255	510	255

It is evident from the foregoing results, that the character of long outer glumes in *E. B. 141* is different genetically from the same observed in *T. 290*. Recently Lien Fang Chao<sup>1</sup> has recorded results showing a 15 : 1 ratio between ordinary outer glume and long outer glume, proving the presence of two duplicate factors for the character. It is probable that there are a number of different genetic factors for the development of the outer glumes in the different varieties of rice.

#### VIII. Inheritance of brown rice.

In the inheritance studies in rice<sup>2</sup> it was explained that two factors A and N are necessary for the production of pigment in the rice plant, and that the presence

<sup>1</sup> For footnotes see page 258.

of one of these, A, is necessary for the production of either, 'red rice' or 'purple rice'. In the absence of factor A, the red rice factor R, produces 'Grey Brown' rice, and the purple rice factor, P, produces 'Brown rice'.

To confirm the anticipated constitution of Purple and Brown rices, an unpigmented plant with brown rice was crossed with a pigmented type with white rice.

Unpigmented plant with brown rice . . . . . aannPP

Pigmented plant with white rice . . . . . AANNpp

The  $F_1$  as expected, was pigmented and had purple rice (AaNnPP).

The  $F_2$  gave four types of plants as shown below:—

	PIGMENTED PLANTS WITH		UNPIGMENTED PLANTS WITH	
	Purple rice	White rice	Brown rice	White rice
	A P N	A p n	a P N	a p n
	309	123	142	53
9:3:3:1 . . .	351	117	117	39

The 9:3:3:1 ratio is represented but the numbers are not near enough to the expected. The results, however, show that the relation between purple rice and brown rice is just the same as that between red rice and grey brown rice. The pigmentation factor A and the purple rice factor P, are both necessary for the production of purple rice, and in the absence of A, factor P, produces brown rice.

<sup>1</sup> loc. cit.

<sup>2</sup> Parnell, F. R., and others. Inheritance of characters in rice, II. *Mem. Dept. Agri. India, Bot. Series*, Vol. XI, No. 8.

## ERRATA.

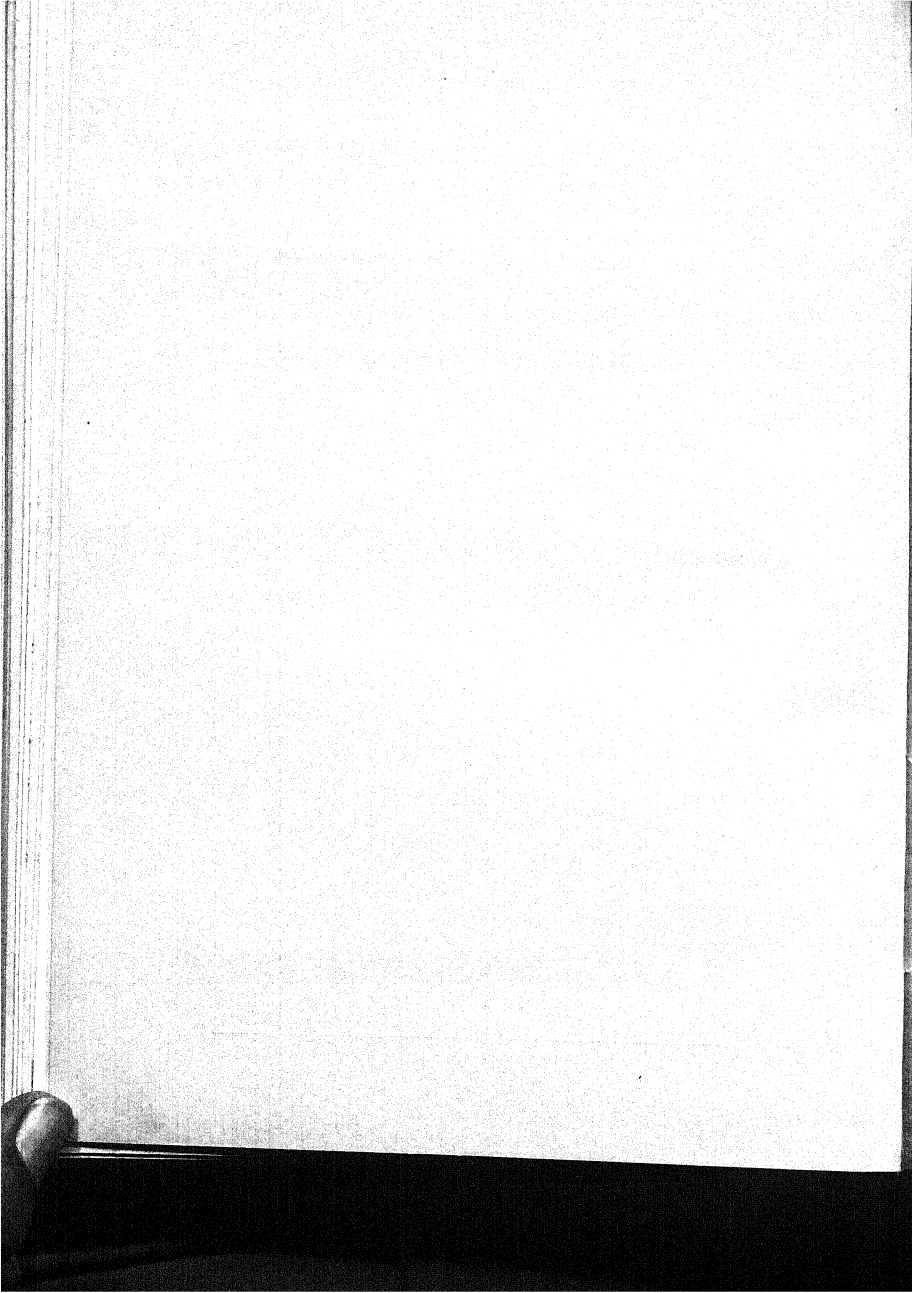
*Memoirs of the Department of Agriculture in India, Botanical Series, Volume XVIII, No. 2 (Root Development in Rice under Different Conditions of Growth, by Mr. R. L. Sethi).*

Page 78, figure 3—letterpress :—

For “anatomy of a land and a water plant of the same Natural order” read  
“anatomy of a land plant of the same Natural order and of a water  
plant.”

Page 78, last line, and page 79, line 1 :—

For “a typical land and a typical water plant of the same order” read  
“a typical land plant of the same order and a typical water plant.”

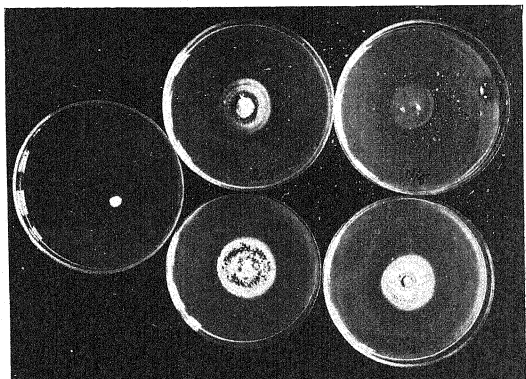


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(a). Disease symptoms. Spots on leaves, leaf-sheath and stem.



(b). Fungal growth in Richard's agar of different concentrations (14 days growth).  
The dish to the extreme left contains 5 N concentration.

# A LEAFSPOT DISEASE OF *ANDROPOGON SORGHUM* CAUSED BY *CERCOSPORA SORGHII* E. & E.

BY

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## I. INTRODUCTION.

A leafspot disease of *Sorghum* (*Andropogon Sorghum*) caused by *Cercospora sorghi* has been prevalent in Coimbatore for some years. It was first observed by the author on the Central Agricultural Station in the year 1921 while examining a *Sorghum* crop in connection with another disease (leaf-shredding disease caused by *Sclerospora graminicola*.) There is no record as to when the disease might have started, but doubtless it must have been in existence much earlier than 1921. Some of the demonstration specimens of *Sorghum* collected about 20 years ago show the presence of a few spots of *Cercospora* disease on the leaves. Hence the disease must have been in existence for a long time. In 1909 Barber (1) noticed certain leaf-spot diseases of *Sorghum* in the Madras Presidency besides rust and anthracnose, but no further investigations are reported, nor is the causal organism mentioned. Probably one of these may be the *Cercospora* leafspot. Since 1921 the disease has been observed every year on the Central Agricultural Station and the neighbouring villages and of late it has increased in virulence.

Ellis and Everheart(2) have recorded in 1886 a disease of *Sorghum halepense* from the United States, the symptoms being noticed on the 'leaves as stripes stained dark purple and several inches in extent.' The causal organism is described as

*Cercospora sorghi* and a short diagnosis of the fungus is given. It was found to affect *Zea Mays* also. From China Porter(3) has recorded a *Cercospora* sp. on *Sorghum* causing a loss of about 5 per cent. Dade(4) has noticed a *Cercospora* on *Sorghum* for the first time in 1925-26 in Gold Coast, while Snowden(5) has observed *Cercospora sorghi* in Uganda. Abbott(6) has recorded a leafspot disease of corn (*Zea Mays*) in Peru caused by *Cercospora sorghi* and it is said to be very common 'causing severe firing or drying of the leaves before they are mature.' He has observed the same fungus causing leafspots on *Johnson grass* and *Holcus halepensis*. The *Cercospora* disease of *Sorghum* has thus been found to be prevalent in many parts of the world. But beyond the diagnosis of the fungus by Ellis and Everheart and the mention of the occurrence of the disease in other parts of the world by the other writers, no detailed study of the disease or the causal organism seems to have been made. In this paper are recorded the characteristics of the disease and the results of the studies on the morphology and physiology of the fungus.

## 2. SYMPTOMS OF THE DISEASE.

The disease usually makes its appearance just at or before the time of flowering. But sometimes plants a month old have also been found attacked. The attack is more severe in the later stages. In Coimbatore two crops of *Sorghum* (grain crops) are raised every year. One called the *Chitrai cholam* is sown about the middle of March and harvested about the end of June or beginning of July. The other, *Periamanjil cholam* is sown in July-August and harvested in December-January. The disease has been found to be very common on the latter crop. But in some years the earlier crop is also affected. In *Chitrai cholam* the disease begins to manifest itself as isolated spots about the middle of May and gradually increases in severity. In the later crop it is evident by the end of October or the beginning of November. In some years even during the last weeks of September the disease has been noticed. Diseases caused by *Cercospora* are generally influenced by the atmospheric humidity. In *Sorghum* the disease is found to increase suddenly after a spell of wet weather.

The disease manifests itself generally as spots on the leaves, the colour of the spots varying on different varieties. The lower leaves are the first to be affected and gradually the infection spreads to the upper ones also. The uppermost leaves have fewer spots than the lower ones. Each leaf becomes covered with numerous spots and very little of the green surface is left. In severely infected cases the whole field presents a reddish blighted appearance. The spots are generally isolated and more elongated than broad. But sometimes a number of spots are formed side by side so as to form diseased patches. The big veins limit the spread of the spots laterally. Isolated spots measure 5-15 mm. in length and 3-5 mm. in breadth. Often several spots occur contiguously when the length extends up to 50 mm. even. When patches are formed by the development of several spots alongside each other,

the breadth varies from 10—15 mm. The spots are amphigenous. To the unaided eye they do not appear sunken, but in sections the affected portions are found to be slightly thinner than the healthy areas.

The colour of the spots varies with different varieties. On plants with dark green leaves the spots are blackish red-purple in colour, while on those in which the colour of the leaves is lighter the spots too become lighter. Thus the depth of the colour of the spots depends upon the intensity of the leaf colour. When the spots are deeper coloured, the central portions present a uniform deep colouration and this is bounded by a lighter coloured red ring. But in the lighter coloured spots the centre is lighter in colour and is bounded by a deeper coloured margin. In some varieties especially those with brown leaf sheaths the spots are not red. To begin with they are yellowish or light brown. But later on they turn somewhat grey with numerous minute black dots on them representing the fructifications. Sometimes these spots are bounded by a yellowish or orange coloured margin. The upper and lower surfaces sometimes vary in colour; the upper surface is deeper in colour than the lower surface or *vice versa*. Very rarely some spots present faint concentric markings. As the leaves turn old and fade in colour the spots appear dark brown or blackish brown.

Besides the leaves, spots are formed on the leaf-sheaths also. On the latter the spots are however bigger than on leaves; the limitation exercised by the veins is not present in the leafsheaths and hence the spots are much broader. Very rarely small reddish spots appear on the stem as well especially at the higher internodes, but these spots remain very small.

This leafspot often occurs mixed up with other diseases as the rust and anthracnose. Though in the first stages they resemble each other, very soon the differences could be easily made out. In the rust the pustules are present in the spotted areas and in anthracnose the centre of the spot becomes straw coloured or whitish with minute black fructifications. These are not noticed in the *Cercospora* leafspot disease.

The disease affects several varieties of *Sorghum*. On the Millets Breeding Station, Coimbatore, the following varieties have been found to be affected—*Chitraivellai*, *Chitraimanjal*, *Periyamanjal*, *Irungu* and *Thalaivirichan*. Besides, several of the selections are also affected. *Chencholam* is also susceptible to the disease.

### 3. MORPHOLOGY OF THE FUNGUS ON THE HOST.

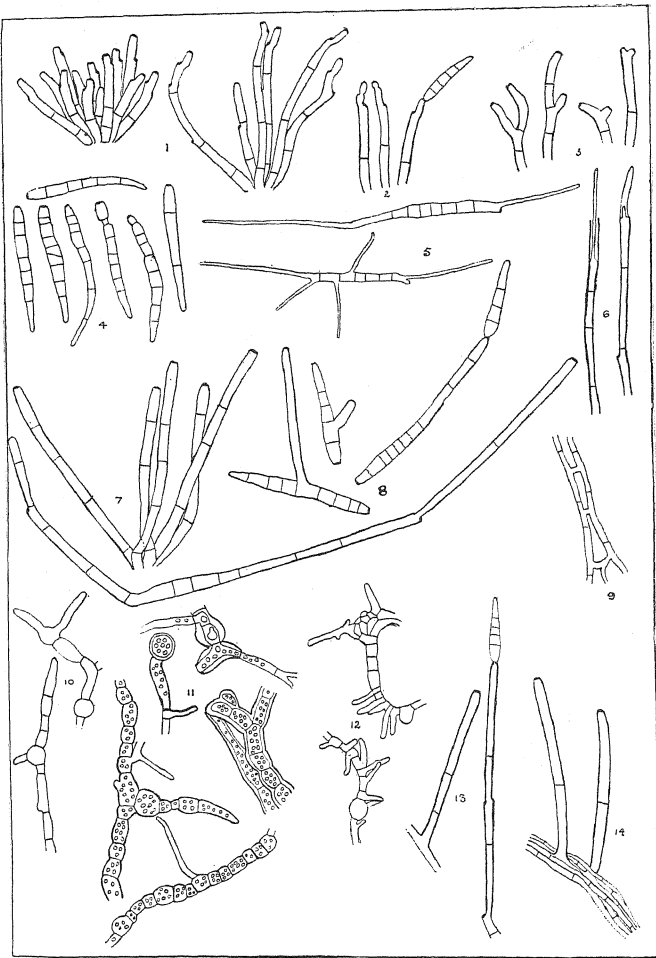
The spots are minute to begin with and gradually increase in size. The fungus mycelium permeates the tissues at the affected spots. The hyphae are at first, hyaline and intercellular but later on may be noticed inside the cells and they turn brown in some regions. They penetrate all the parenchymatous cells of the mesophyll, but are not found inside the vessels or the sclerenchymatous cells. Above and below each big vein sclerenchymatous bands extend from the epidermis to the

vascular bundles and these prevent the lateral expansion of the fungus. In the affected portions the cuticle and the sclerenchymatous cells are deeply stained red at first and the other cell walls gradually assume a lighter tint. The red colour could be noticed a little distance beyond the portion invaded by the hyphae. To begin with the mesophyll cells lose the green colour, turn light brown and shrink in size to a little extent. In later stages the discolouration deepens and the cells disintegrate. In sections the two epidermal layers become easily torn apart with the disintegrated cells and the vessels sticking to them. Plenty of hyphae could be noticed at this stage. The hyphae collect underneath the stoma and form a stromatoid structure which is sometimes found to be projecting out of a stoma. The size of this structure varies according to the number of conidiophores borne.

Inside the leafsheath also the hyphae pass both between and across the parenchymatous cells. The walls of the epidermal cells and the sclerenchymatous cells are deeply stained red, while the walls of the parenchymatous cells are lighter coloured.

When the spots are pretty old, conidiophores and conidia are formed on both the surfaces of the spots being produced all over except for some distance round the margin. The conidiophores on the surface of old spots appear as a brownish mass *en masse*. They are produced in clusters, the number in each cluster varying from 3 to 4 to as many as 16. They emerge through the stomata and clusters may be found to come out through most of the stomata. Each cluster has at its base a stromatoid structure made up of brown coloured cells. From these the conidiophores originate. Each conidiophore is usually unbranched, but a number of branched ones also occur. The branches arise either from the base or the upper portions. The conidiophore is septate and of a dark brown colour. Conidiophores from specimens collected on a comparatively dry day measured on an average  $71.5 \times 4.6 \mu$  (the limits being  $39.4-118.3 \times 2.9-7.3$ ). The number of septa varies from 0-5, the mode being 2. At the apex, each conidiophore presents a number of characteristic bents. At each bent there is a scar left by a spore. The scar appears as a slightly thickened area and looks darker under the microscope. The number of scars represents the number of spores produced and 1 to 6 scars may be noticed on a single conidiophore. The conidia are developed at the tips of the conidiophores. After one conidium has been formed, the stalk elongates past the conidium producing another again and thus the bents are formed.

Owing to the formation of the conidia, the surface of the spot presents a greyish white velvety appearance. The conidia are hyaline, many septate and elongated, broader at the base and tapering towards the apex. At the base of the conidium a scar is present showing the place of attachment to the stalk and this appears as a darker area. The conidial wall is usually smooth but rarely constrictions are formed at the septa. Moisture conditions affect the size of the conidia. On an average they measure  $73.1 \times 5.8 \mu$  (the limits being  $30-132 \times 3-8$ ). Septation varies from 1-12, the mode being 6. The conidia are usually hyaline, but some old ones are of



1. Conidiophores from nature. 2. Conidium formation. 3. Branched conidiophores. 4. Conidia. 5. Germination of Conidia. 6. Germination of conidiophores. 7. Conidiophores in moist air. 8. Conidia giving rise to conidiophores and conidia. 9. Hyphal connections. 10. Swollen cells of hyphae in French bean agar. 11. Hyphal peculiarities and chlamydospore like bodies on sorghum leaf. 12. Hyphae from liquid cultures. 13. Individual conidiophores from culture. 14. Conidiophores given off from hyphal strands (all  $\times 270$ ).



brownish tint. Sometimes one or two of the cells of the conidium are shrunken. The length, breadth and septation of the conidiophores and conidia are shown in figure 1.

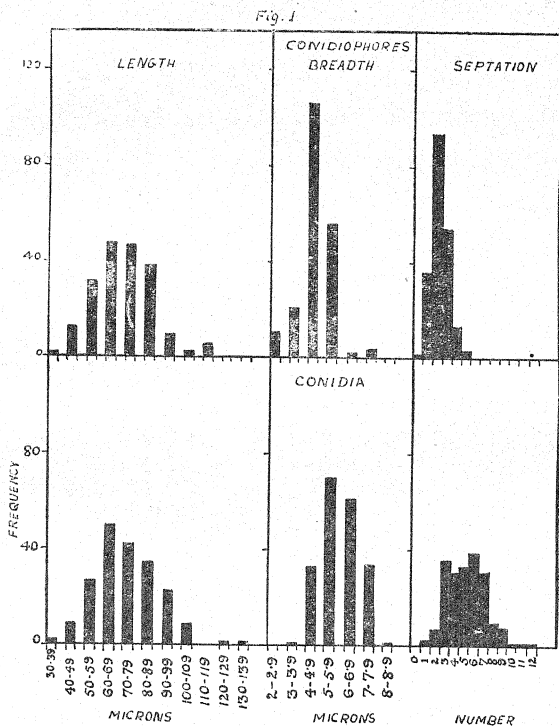


Fig. 1. Graphical representation of the length, breadth and septation of the conidiophores and conidia collected from nature.

Both the conidiophores and the conidia are capable of germination. When placed in drops of water, the germ tubes begin to appear in the course of two-three

hours. They originate from the ends of the conidiophores. If the latter are broken, the germ tube forms internally from the septum and comes out through the broken end. The conidia germinate by giving rise to a number of germ tubes, each cell being capable of producing one. Some conidia, instead of forming germ tubes which continue into mycelial growth, directly give rise to conidiophores. Generally conidia which have been rather old and lying for a long time on the surface of the leaves or cultures are found to have germinated in this manner. Such conidia are also slightly coloured. These conidiophores develop from the terminal cells at either ends of the conidium and are either short or elongated. Rarely, the conidiophores develop laterally from the conidium. These are coloured brown and bear normal conidia.

#### 4. PATHOGENECITY OF THE FUNGUS.

(a). To prove the pathogenicity of the fungus on *Sorghum*, several inoculations were made on the leaves of healthy *Sorghum* plants which were grown in pots. The leaves were first washed with sterilised water. Suspensions of spores collected from diseased plants and from cultures were placed on the leaves. Before inoculation the leaves were wounded in some plants by pin pricks or by the scraping of the epidermis by a sharp scalpel, while in others the leaves were unwounded. The inoculated leaves were enclosed inside glass chimneys whose ends were plugged with moistened cotton wool. The cotton wool was always kept moist to keep up a humid atmosphere inside. On wounded leaves red spots were visible on the 4th day, while on the unwounded leaves it took 7—8 days for the spots to develop. On the former, spores were formed on the 7th day, while on the latter they were noticed only on the 12th day. These experiments were repeated using bits of culture with plenty of mycelium instead of spores. Similar results were obtained. In both cases 6—8 out of 10 inoculated plants took infection, much quicker on wounded leaves than on unwounded ones. The controls remained healthy throughout. Plants in various stages of growth were infected, thus showing that *Sorghum* is capable of being affected in all stages.

(b). In order to find out the manner of penetration, suspensions of spores were kept on the leaves and examined periodically. On the 3rd morning the conidia were found to have germinated with the germ tubes ramifying in all directions. Some of these had actually passed over stomata without entering them, while others were found to have penetrated through the stomata. No case of piercing through the epidermal cell wall was noticed. In the region over which the hyphae had spread it was found that the guard cells of several of the stomata had assumed a red tint. In sections of infected portions in the early stages the cuticle on the epidermal cells was found to have turned red though the cells themselves did not show the presence of fungal hyphae. Probably the fungus secretes some substance which brings about the change in the colour.

(c). Inoculations were conducted on the leaves of other plants known to be parasitized by *Cercospora*. Groundnut, maize, egg plant, tobacco and sugarcane were the plants selected. Inoculations were made on both wounded and unwounded leaves. No infection was noticed in any except in the case of wounded sugarcane leaves in which reddish spots developed in 2 out of 8 inoculated leaves. The parasitism of the fungus appears to be restricted.

Ellis and Everheart(2) have recorded the fungus on *Zea Mays* on which it causes leafspots. Abbott(6) writes that in Peru one of the important diseases of maize is caused by *Cercospora sorghi*. But the inoculations with the local strain on maize leaves were not successful. Further maize was being grown on the Central Agricultural Station, Coimbatore, in a field next to one having *Sorghum*, the two being separated only by a narrow ridge. The *Sorghum* crop was heavily diseased but no signs of disease caused by *Cercospora* were found on maize. This fact coupled with the failure to infect maize by artificial inoculation goes to show that the local strain of the fungus is not parasitic on maize.

Under laboratory conditions spores from specimens collected five months back were found to have lost their capacity for germination. But spores 2 to 2½ months old retain their viability.

#### 5. CULTURAL STUDIES OF THE FUNGUS.

(a). This fungus can be cultivated on a number of culture media. A comparative study of the nature of the growth of the fungus on some of them was made. Attention was directed at first towards a comparison of the growths on the usual plant extract agars that are employed in the laboratory such as French bean, Quaker oats and rice meal agars. In addition *Sorghum*-leaf-extract agar and sterilised *Sorghum* leaves, leafsheaths and stem were also used. The effect of the composition and concentration of the media on the growth of the fungus was next investigated. For this purpose, synthetic media had to be used. Since Richard's agar was found well suited for the growth of the fungus it was employed. Sucrose and *Sorghum*-leaf-extract agars of different concentrations were also utilized.

The growth was studied in Petri dish cultures. The dishes were ordinarily of the same size and the same amount of medium was used for each dish. Comparisons were made by noting the radial advance in Petri dish cultures and in some cases also by finding out the dry weight of the fungus in liquid cultures. For the latter purpose the cultures were made in 100 c.c. flasks. 50 c.c. of the cultural liquid was used in each case. Duplicate cultures were always set up and the averages determined. pH values were determined by the colorimetric method. The cultures were kept at the laboratory temperature. The variations in the temperature of the laboratory during the time of each experiment are noted within brackets under each.

(b). On all the media the fungus made a slow growth. This feature has been found to be characteristic of other species of *Cercospora* also (7). It takes more than

four weeks to spread over the whole dish (80 mm. in diameter). The cultural characteristics of the fungal growth on the media were as follows (72°—84° F.) :—

TABLE I.

Medium	Macroscopic characters	Microscopic characters
French bean agar . . . .	Aerial growth good, a mixture of white and grayish-olive in colour, submerged growth thick matted olivaceous black, concentric zones formed, numerous sclerotial bodies.	Hyphal strands sometimes sticking up, intercalary swollen thin walled cells present, conidiophores and conidia formed.
Quaker oats agar . . . .	Aerial growth good, white and grayish olive with a touch of pink in some places, submerged growth of a darker colour, zones present, sclerotial bodies.	Hyphal strands, conidiophores and conidia formed.
Rice meal agar . . . .	Aerial growth loose and more profuse, smoke gray to grayish olive, submerged growth dark ivy green, zones very faint, not seen on the reverse, sclerotial bodies.	Hyphal strands, conidiophores and conidia developed, young hyphae sometimes beaded in appearance.
<i>Sorghum</i> -leaf-extract agar (2 per cent. agar plus 250 gms. of leaves per litre).	Good aerial growth, pale smoke gray, submerged growth olivaceous black, zones present, a halo of darker colour in the medium round the fungal growth, sclerotial bodies absent.	Hyphal strands, conidiophores and conidia formed.
Sterilised <i>Sorghum</i> leaves .	Aerial growth loose, pale smoke gray to smoke gray, tissues blackened.	Abundant spore formation, sclerotial bodies formed, swollen thick walled chlamydospore-like bodies present.
Sterilised <i>Sorghum</i> stem .	Aerial growth denser, white at first but later smoke gray, tissues blackened.	Sclerotia formed.

On agar media the fungus made a compact growth consisting of a thick matted submerged portion and a loose aerial growth. The aerial hyphae are hyaline when young but with age develop a light grayish olive colour. The submerged hyphae are hyaline only for a short time and soon turn into shades of olive brown. Individual hyphae are not usually deep coloured; but since they form a thick growth, the whole mass appears olivaceous black when seen from the underside of the Petri dish. At the edge of the growth there is a cartridge buff coloured margin about 3 mm. in width and made up of young hyphae. The hyphae anastomose freely and H connections are very common. On most of the media several hyphae come to lie side by side and become united into strands. These sometimes stick up from the medium. Sclerotoid bodies are common on French bean, oat and rice meal agars and on *Sorghum* tissues. These originate by the close association and intertwining of numerous short branches of more than one hyphae lying in close proximity. On agar media these are greenish at first and become black with age. On

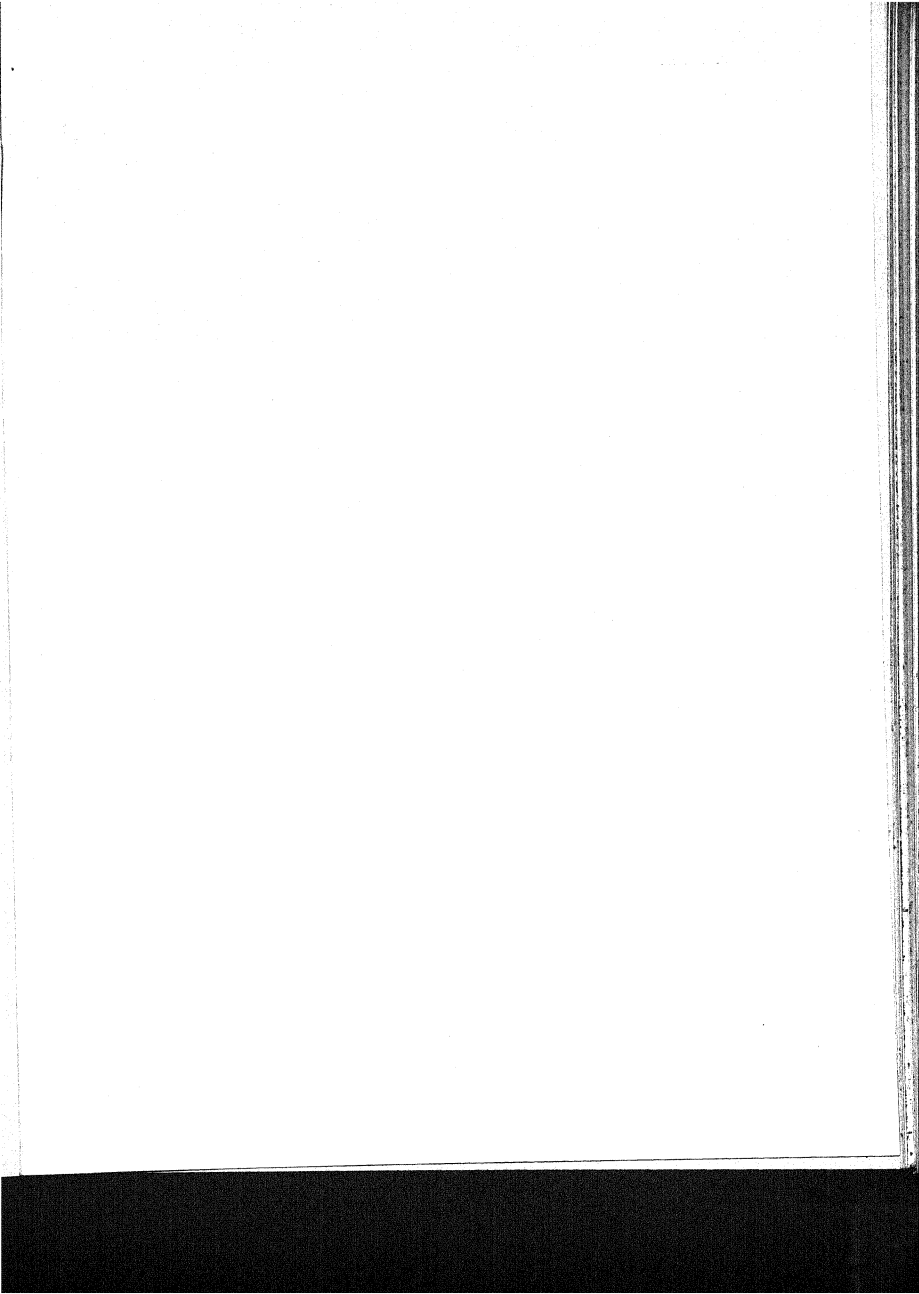
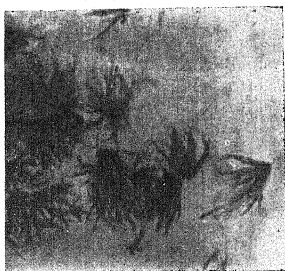
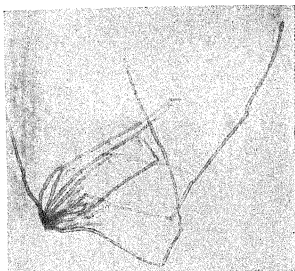


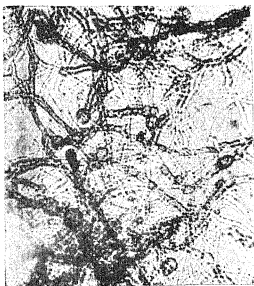
PLATE III.



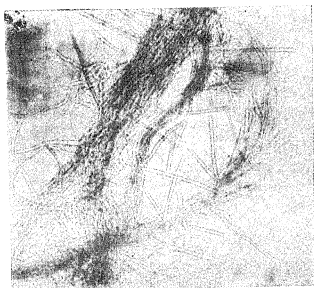
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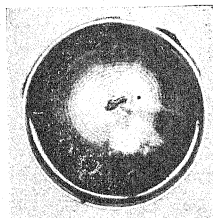
4.



5.



6.



7.

Photomicrographs of—1. Conidiophores and conidia from nature. 2. A cluster of conidiophores after 48 hours in moist chamber. 3. Swollen chlamydospore like bodies in the hyphae. 4. Mycelial strands and conidiophores from French bean agar. 5 & 6. Sclerotial bodies on autoclaved sorghum leaves. 7. Photograph showing zonation in sorghum leaf extract agar (18 days old).

*Sorghum* tissues they are more brownish to begin with and later on turn black. Older hyphae sometimes develop rounded intercalary or terminal swollen thick walled cells of deep olive brown colour containing highly refractive bodies. Often such cells are formed in chains. Probably these serve as chlamydospores. Lehman (8) has observed certain structures comparable to these in the older mycelium of *Cercospora diazi maru* on potato agar.

Conidiophores are formed in the aerial growth and not in the submerged portion. They arise usually as lateral branches of hyphae but very often they are produced in large numbers from the hyphal strands. The formation of conidiophores is mainly confined to the central portion of the growth and gradually diminishes towards the circumference. They are smoky brown in colour but the depth of the colour varies with the medium. Those on rice meal agar are deepest coloured. They are septate much elongated, 200 to 400 $\mu$  in length, thin and straightened. Each one produces a number of conidia and up to 7 have been noticed in some. The distance between the successive bents or spore producing places was 95 $\mu$  in some cases. Spores are produced in large numbers on several media but with the age of the culture the sporulating capacity diminishes.

(e). It was noticed that the conidiophores produced on the media are usually bigger and have a larger number of septa than those collected from nature. This might be attributed either to the influence of the medium or to the humidity inside the Petridishes. It has been noticed in other species of *Cercospora* that humidity influences the size of the spores and the sporophores (7). To find out if the same holds good with this fungus, fresh specimens of diseased leaves were collected, cut into convenient bits, each having a number of spots on it and placed in open Petri dishes inside sterilized moist chambers. Measurements of the conidia and conidiophores were made from other specimens collected at the same time. After 24 hours some of the bits were removed from the moist chamber and the measurements of conidiophores and spores noted. Similarly, measurements were made after 48 hours and 72 hours. Fig. 2 shows the average length, breadth and septation of the conidiophores and conidia after exposure for different lengths of time to a saturated atmosphere. The conidiophores show an enormous increase in length doubling themselves in 24 hours and reaching nearly 4 times the original size in 72 hours. At the same time there is a slight decrease in breadth probably due to the rapid elongation. The number of septa has necessarily increased, the longer conidiophores having a larger number of septa. Just as in the case of conidiophores formed on the agar media, here too the distance between two successive bents or spore scars is great measuring up to 140 $\mu$  in some cases especially after 72 hours in the moist chamber. In the case of the conidium also a pronounced increase in length and septation is noticed after 24 hours, but in breadth the increase is not appreciable. Another point to be noted is that spores from specimens removed after 48 and 72 hours do not show any appreciable increase and are smaller than those of 24 hours exposure. This could be explained by the fact that numerous fresh conidia have

developed in the meanwhile and have come in for measurement before reaching their maximum development. This must account for the reduction in size found after 48 and 72 hours. Thus increased humidity results in the increase in the length of the conidiophores and conidia. In the former the length increases as the time of exposure to a humid atmosphere is lengthened.

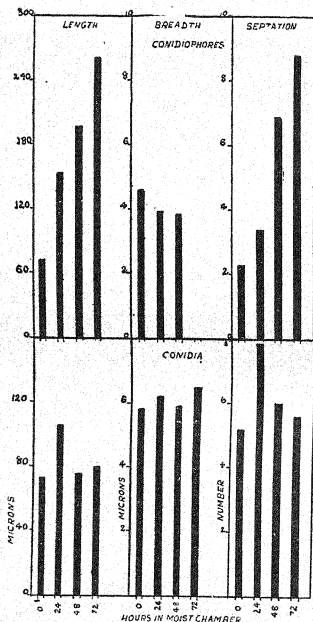


Fig. 2. Comparative measurements of conidiophores and conidia when dry and after exposure for 24, 48, and 72 hours to a humid atmosphere.

(d). Concentric zones were noticed in all the plates faintly in some and distinctly in others. When the number of zones was counted in each plate it approximated to the number of days of growth. Zones have been noticed in the growths of other fungi and the formation of these has been attributed to various causal agencies "to light relation, to nutrients, to agencies other than light probably food, to resting

periods and to mycelial crowding" (10). Brown(9) has observed in the growth of certain strains of *Fusarium* "definite series of rings corresponding to the alternation of day and night." In this fungus also the formation of the zones is due to light relation. Inoculations were made on the four agar media. One set of cultures was kept opposite a northern window in the laboratory, while another set was kept inside a dark chamber ( $72^{\circ}$ – $84^{\circ}$  F.). The zones were absent in cultures kept in complete darkness, while in those kept outside exposed to light during the day the zones were quite distinct. So the zonation is caused by the alternation of light and darkness during the day and night respectively.

Spores were formed in both the series of plates. No distinct difference could be made out regarding the intensity of sporulation. Measurements of spores from French bean, rice meal and *Sorghum*-leaf-extract agars kept under the two different conditions were made. Though there is slight variation between certain of the measurements, no definite influence of complete darkness on spore size could be noticed.

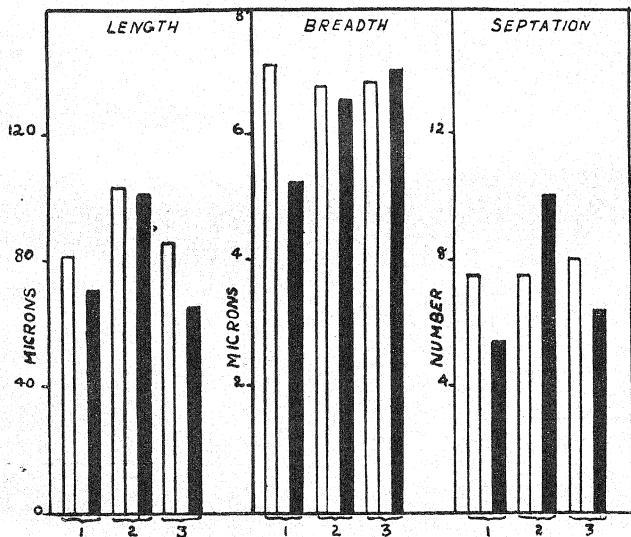


Fig. 3. The average length, breadth and septation of spores from (1) *Sorghum*-leaf-extract, (2) rice meal and (3) French bean agars exposed to light and darkness. (Measurements from those kept in darkness are coloured black).

(c) *Change in the reaction of the medium.* The fungus was grown in Richard's solution and the changes in the reaction of the medium were noted by determining the pH value of the medium at intervals of 10 days. pH values were determined for the control flasks also (82°—94° F.). Below are given the results.

TABLE II.

*Inoculated on 27th March 1929.*      *pH value of the medium at start 3.8.*

Date of examination	pH of control	pH of inoculated flask
6th April 1929 . . . . .	3.8	4.5
16th April 1929 . . . . .	3.8	6.2
26th April 1929 . . . . .	3.8	6.6
6th May 1929 . . . . .	3.8	6.7

The medium is rendered less and less acid as the growth of the fungus increases.

*Effect of the reaction of the medium.* This was determined in two ways. One was by noting the diameter of the growth at intervals on Richard's agar of different Fuller's scale and the other by finding out the weight of the fungus growth in Richard's solution of different pH values.

The characteristics of the growth (78°—86° F.) on Richard's agar of different Fuller's scale were as follows:—

TABLE III.

Fuller's scale	Diameter in mm. in 16 days	Diameter in mm. 18 days	REMARKS
—15	20	32.5	Aerial growth poor with a few radial folds, powdery, olive gray with a margin of cartridge buff, on the reverse more of pinkish buff with a little of deep olive, no spores.
N	33	36.5	Aerial growth better, powdery, a mixture of deep olive and olive gray with white, lighter towards margin, reverse deep olive surrounded by cartridge buff, no spores.
+10	35	38.5	Aerial growth good, deep olive gray in centre, lighter towards margin, reverse olivaceous black, few spores.
+20	36.5	41	Best and thick growth, whitish mixed with olive gray reverse olivaceous black with buff margin, more spores.
+33	35.5	41	Same as in +20.

Table IV gives the results obtained with liquid cultures (78°—87° F.).

TABLE IV.

Original pH value	pH of control	pH after 35 days growth	Weight of fungus in grams
9.4 . . . . .	8.4	8.7	.101
7.4 . . . . .	7.4	8.5	.235
6.8 . . . . .	6.8	7.5	.260
5.8 . . . . .	5.8	7.5	.390
4.6 . . . . .	4.6	7.1	.359

The fungus thrives well in an acid medium and there is a reduction in growth as the acidity decreases. The best growth occurs between +20 and +33 Fuller's scale or about pH 5.8.

(f). *Effect of concentration of medium on growth.* First the effect of increasing the strength of *Sorghum*-leaf-extract on the growth was noted. The extracts were prepared by adding 6, 15, and 20 grms. respectively of cut leaves to 150c.c. of water and boiling. A portion of the extract was put in flasks to serve as liquid medium and to the rest 3 per cent. agar was added. The radial advance of the growth was noted on solid media and the weight of the fungus in liquid cultures ( $82^{\circ}$ – $94^{\circ}$  F.).

TABLE V.

No. of days growth	Concentration		
Diameter in 21 days . . . .	6/150 29.5 mm.	15/150 34 mm.	20/150 33.5 mm.
Weight in 35 days . . . .	.015 grms.	.053 grms.	.070 grms.

On agar media the lowest concentration shows the least growth, while the other two are alike. In 6/150 the growth is thin. Spores are formed in all the three concentrations. In liquid cultures the weight is found to increase with the concentration. The media develop a darker colour after the growth of the fungus. On agar media a darker band is formed round the fungal growth.

Different concentrations of cane sugar in the medium were next used. For this purpose media containing 1 per cent., 2 per cent., 3 per cent., 4 per cent. and 5 per cent. sugar, respectively, with 2 per cent. agar were made. The diameter of the growth was noted at regular intervals ( $73^{\circ}$ – $86^{\circ}$  F.). Figure 4 shows the results.

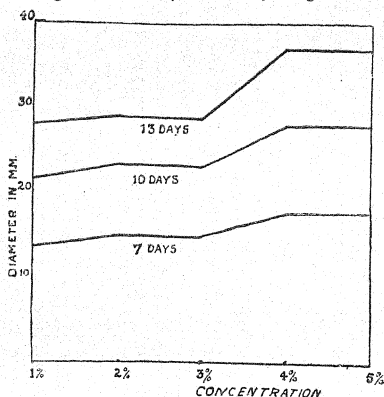


Fig. 4. Diameters of fungus growths on agar containing different percentages of sugar.

The rate of advance is almost uniform. 1 per cent. shows the least growth. In 2 per cent. and 3 per cent. the growths are equal but more than in 1 per cent. There is no difference between 4 per cent. and 5 per cent. but the growth is more than in 3 per cent. In all the growth is thin and sparsely aerial and coloured deep grayish olive. The submerged hyphae are irregularly swollen and full of granular contents. Spores are formed on all the media but in 4 per cent. and 5 per cent. the intensity was less. The measurements of the spores exhibit a slight reduction in size in 5 per cent. But between the other concentrations the difference is not appreciable (Fig. 5).

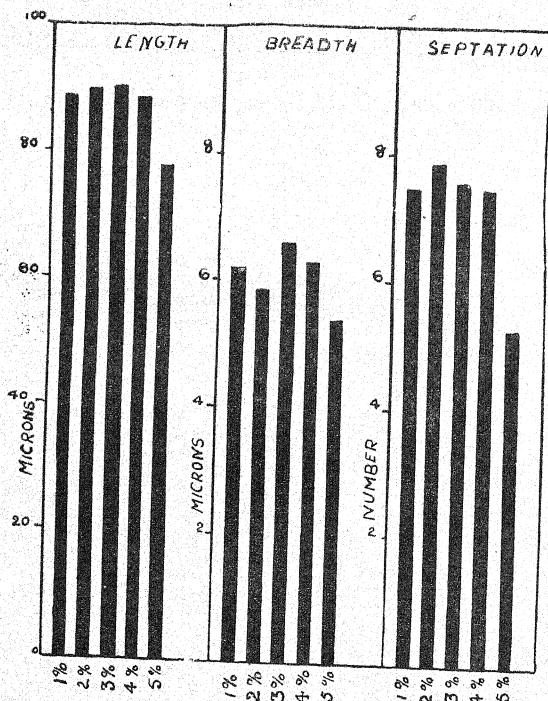


Fig. 5. Average measurements and septation of spores from media containing different percentages of sugar.

Richard's solution of different concentrations was also employed to note the effect on growth. 5 concentrations of the medium were used, *viz.*, 5N, 2N, N, N/2, and N/5 where N represents the normal strength. Cultures were made on solid and liquid media (the former by the addition of 2 per cent. agar to the medium). Fig. 6 represents the diameter on solid media (76°—86° F.).

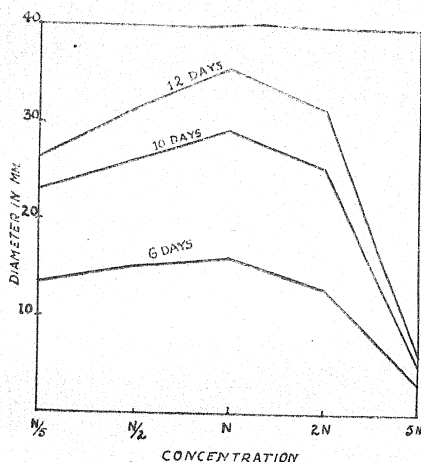
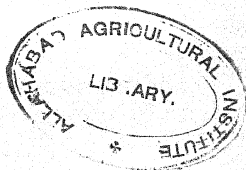


Fig. 6. Diameters of growths on Richard's agar of different concentrations.

On solid media the growth is found to be most in the normal concentration and there is a falling off on either side, but that towards the higher concentration is more steep and sudden. In N/5 the growth is very thin and white with little aerial mycelium. In N/2 the growth is thicker and more compact, grayish olive in the centre and whitish outwards turning light grayish olive towards the circumference. The submerged growth is olivaceous black. N shows the best growth with plenty of aerial mycelium and clumps of hyphal strands sticking up. The aerial growth is grayish olive mixed with white and the submerged growth is olivaceous black. In 2N the growth is less than in N. The central aerial growth is white surrounded by grayish olive and the edges are pale pinkish buff. The submerged growth is less deeply coloured than in N. The growth in 5N is the least with very little of white aerial mycelium.



With liquid cultures also similar results are obtained. In 5N are developed submerged flocculent masses of mycelium white in colour slightly tinted green. In the others a crust is formed in addition on the surface of the liquid, the depth of the colour and the thickness of the crust varying on either side of the normal. The weights of the growths recorded after 30 days are as follows :—

TABLE VI.

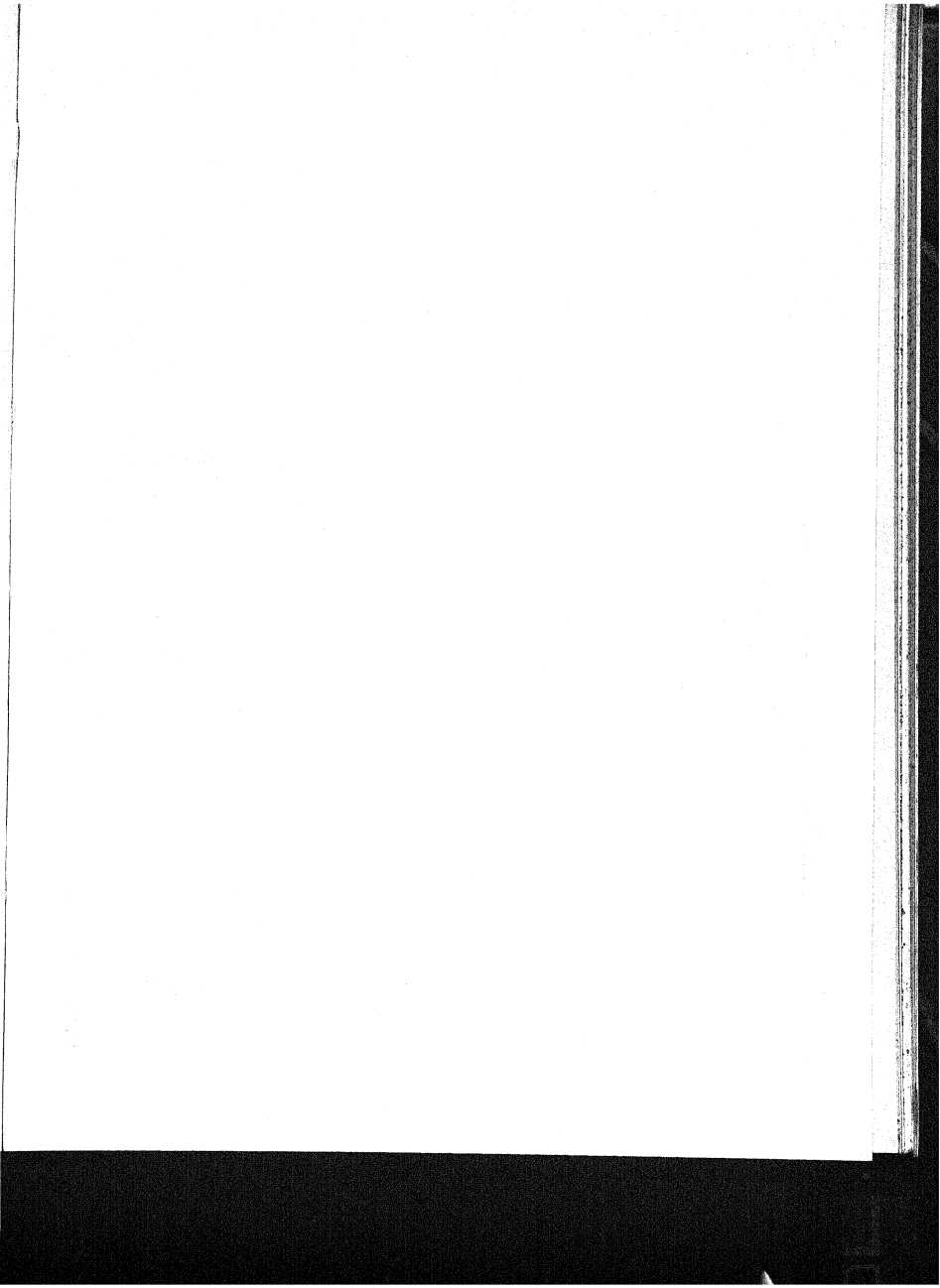
Concentration	pH of control	pH of inoculated medium	Weight of the fungus in grms.
N/5 . . . . .	4.0	8.2	.139
N/2 . . . . .	4.0	8.2	.398
N . . . . .	4.2	8.3	.569
2N . . . . .	4.2	6.1	.325
5N . . . . .	4.2	4.6	.026

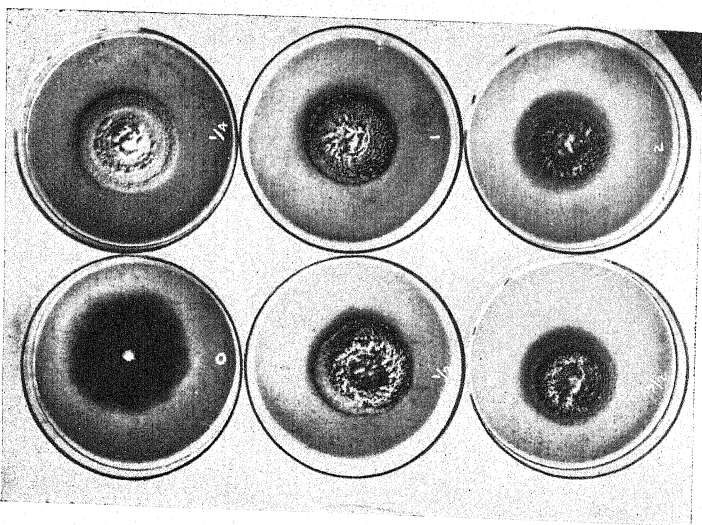
(g). *Effect of removal of different constituents from Richard's medium.* The effect of the removal of various components on the growth of the fungus was determined. Both liquid and solid media (by the addition of 2 per cent. agar to the solution) were used. Below are the results obtained in both the cases (82°—94° F.).

TABLE VII.

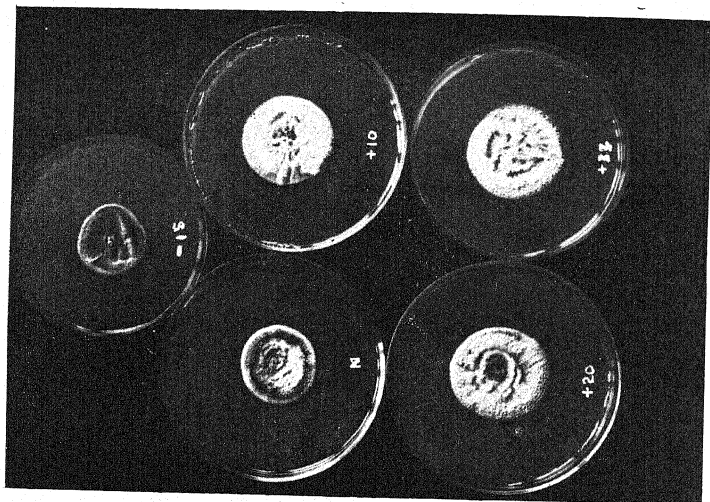
No. of days growth	Normal	—FeCl <sub>3</sub>	—KH <sub>2</sub> PO <sub>4</sub>	—MgSO <sub>4</sub>	—K NO <sub>3</sub>	—Sugar
Diameter in mm. 12 days .	28.5	25.5	24	24.5	33.5	18
Weight in grms. 28 days .	.302	.242	.144	.124	.036	..

Sugar is the most important component of the medium. In the absence of sugar the growth was very thin with few aerial hyphae on solid media and in liquid cultures there was practically no growth. Next to sugar K NO<sub>3</sub> seems to be most essential. In the absence of K NO<sub>3</sub> a thin greenish black growth with scanty aerial hyphae resulted on agar media. Though the diameter of the growth was the greatest, it was very thin and the hyphae were coloured and full of granular contents. In the liquid medium the growth consisted of submerged roundish masses of light green mycelium. On solid media there was not much difference in the radial advance of the growths on those lacking in ferric chloride or MgSO<sub>4</sub> or K H<sub>2</sub>PO<sub>4</sub>. But liquid cultures showed that the absence of ferric chloride was much less felt





(a). Growth on Richard's agar with different concentrations of nitrate (17 days old).



(b). Growth on Richard's agar of different Fuller's scale (18 days growth).

than either  $\text{MgSO}_4$  or  $\text{KH}_2\text{PO}_4$ . In normal medium the fungus showed the best growth. In normal and other liquid cultures the submerged growth was white but in the absence of nitrate it developed a greenish colour.

(h). *Growth reaction with different strengths of  $\text{KNO}_3$  in Richard's medium.* Next was studied the effect of varying amounts of nitrate on the growth of the fungus. Richard's solution with no nitrate and  $\frac{1}{4}$ ,  $\frac{1}{2}$ , 1,  $\frac{3}{2}$  and 2 times the normal amount of  $\text{KNO}_3$  were prepared. A portion was kept as liquid medium and to the other  $2\frac{1}{2}$  per cent. agar was added.

On solid media the growth in those lacking in nitrate is thin and greenish black with a few coloured aerial hyphae. The diameter of the growth is, however, the greatest. In  $\frac{1}{4}$  nitrate the growth is fairly thick and matted with plenty of aerial mycelium varying in colour from smoke gray to white and having a mealy appearance. The submerged growth is olivaceous black with cartridge buff coloured margin. In both  $\frac{1}{4}$  nitrate and 1 nitrate a very thick growth is produced with numerous hyphal clumps sticking up besides light grayish olive and white aerial mycelium. The submerged growth is olivaceous black with cartridge buff margin. In  $\frac{3}{2}$  and 2 nitrate the growth though thick has less of aerial mycelium. In the centre are clumps of hyphae but towards the margin the surface is smooth and pale pinkish buff with few clumps. The submerged growth also shows a reduction of the olivaceous black colour and an increase of the cartridge buff colour.

On solid media there is a gradual decrease in diameter with the increase in concentration but above  $\frac{1}{2}$  nitrate the diameters are almost equal. One peculiarity is noted about the production of the aerial clumps in the higher concentrations. These are produced in rings with a twisting in the anti-clockwise direction. The weights of the fungus growth in the liquid media show that  $\frac{1}{4}$  and  $\frac{1}{2}$  nitrates are nearly equal and there is a fall on either side of them. The fall is gradual with the increase in concentration but is sudden on the zero side. Below are the results ( $78^\circ$ — $86^\circ$  F.).

TABLE VIII.

No. of days growth	$\text{ONNO}_3$	$\frac{1}{4}\text{NO}_3$	$\frac{1}{2}\text{NO}_3$	$1\text{NO}_3$	$\frac{3}{2}\text{NO}_3$	$2\text{NO}_3$
Diameter in mm. 14 days	49	40	38	37	35.5	36
Diameter in mm. 16 days	56	46	45	44	43.5	43
Weight in grms. 30 days	.006	.449	.451	.333	.248	.188

*Temperature.* During the hot months of the year the growth of the fungus in culture is very slow. Naturally this must be attributed to the high temperature prevailing during that period. The maximum temperature in the shade goes up to  $100^\circ$  F. on some days. It was not possible to grow the fungus at different temperatures to find out the optimum. But the effect of exposing the culture to a tempera-

ture of 37°—38° C. (98.6°—100.4° F.) inside an incubator was noted. Controls were kept outside where the variations were between 82°F. and 94°F. Even after 20 days no growth had taken place in the dishes kept in the incubator, while those kept outside showed good growth. Hence the slow growth obtainable during the hot months must be attributed to the high temperature prevailing during parts of the day when the growth would be retarded or even stopped and could continue only during the cooler hours.

One phenomenon that was noticeable in these experiments was that in comparing the fungal growths in different concentrations the radial advance alone was not a sure indicator of the amount of fungal growth. For in some the growth was thin and in others thick. In such cases it was necessary to combine this method with the determination of the weights of the fungal growths from liquid medium. In certain cases, however, the radial advance alone gave reliable results.

## 6. SUMMARY.

A leafspot disease of *Andropogon Sorghum* caused by *Cercospora sorghi* has been prevalent in and around Coimbatore for some years. The symptoms of the disease and the morphology of the fungus are described. The disease affects a number of varieties. The fungus did not infect maize though in other countries it has been found to do so.

Concentric zones are developed in cultures but these are not formed in those kept in darkness. Spores are formed in cultures. Growth in complete darkness does not affect the spore size.

The fungus renders the medium on which it grows alkaline. Media of +20 Fuller's scale or pH 4—6 are best suited for the growth of the fungus.

Using Richard's medium, it was found that the growth of the fungus is much retarded if the concentration is increased above normal, while dilution also affects the growth but to a lesser extent.

Sugar and  $KNO_3$  are quite essential for the growth of the fungus and if either is removed from Richard's medium the growth is markedly affected, more so if the former is absent.

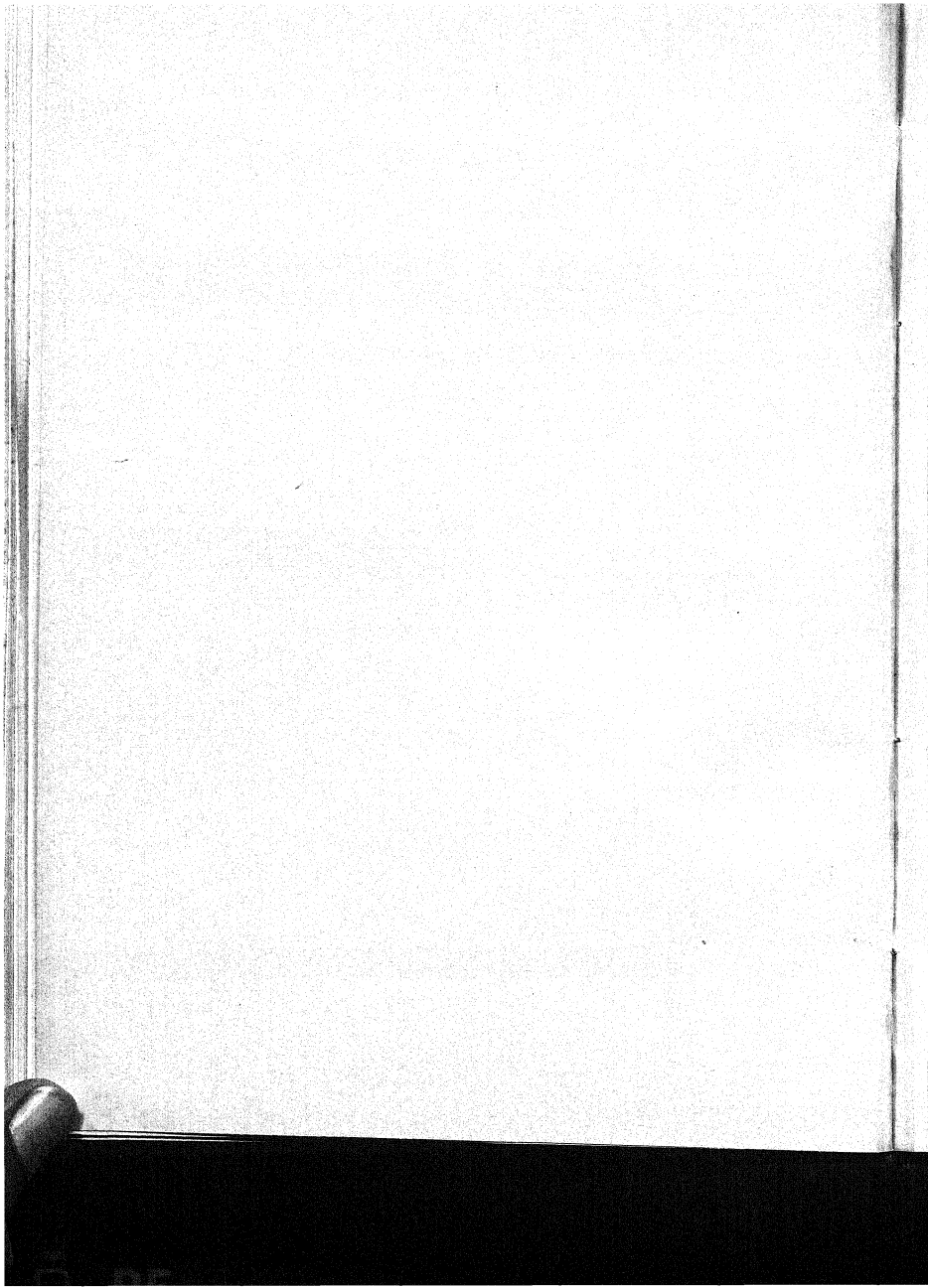
When different amounts of  $KNO_3$  are added to Richard's medium, it is found that either the absence or too much of it affects the growth, the latter to a lesser extent.

The fungus does not grow at a temperature of 37°—38°C.

*Acknowledgments.* My thanks are due to Messrs. P. H. Rama Reddi, the Principal, P. S. Jivanna Rao, Lecturer in Botany and S. Sundararaman, Government Mycologist, for affording all facilities and rendering help in this investigation. I am indebted to Mr. P. D. Karunakar, Agricultural Bacteriologist, for helping me in determining the pH values of the media and to Mr. G. N. Rangaswami Iyengar, Millets Specialist, for allowing me to study the disease in his station.

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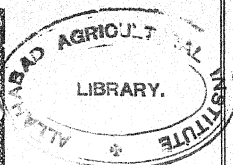
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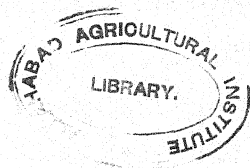
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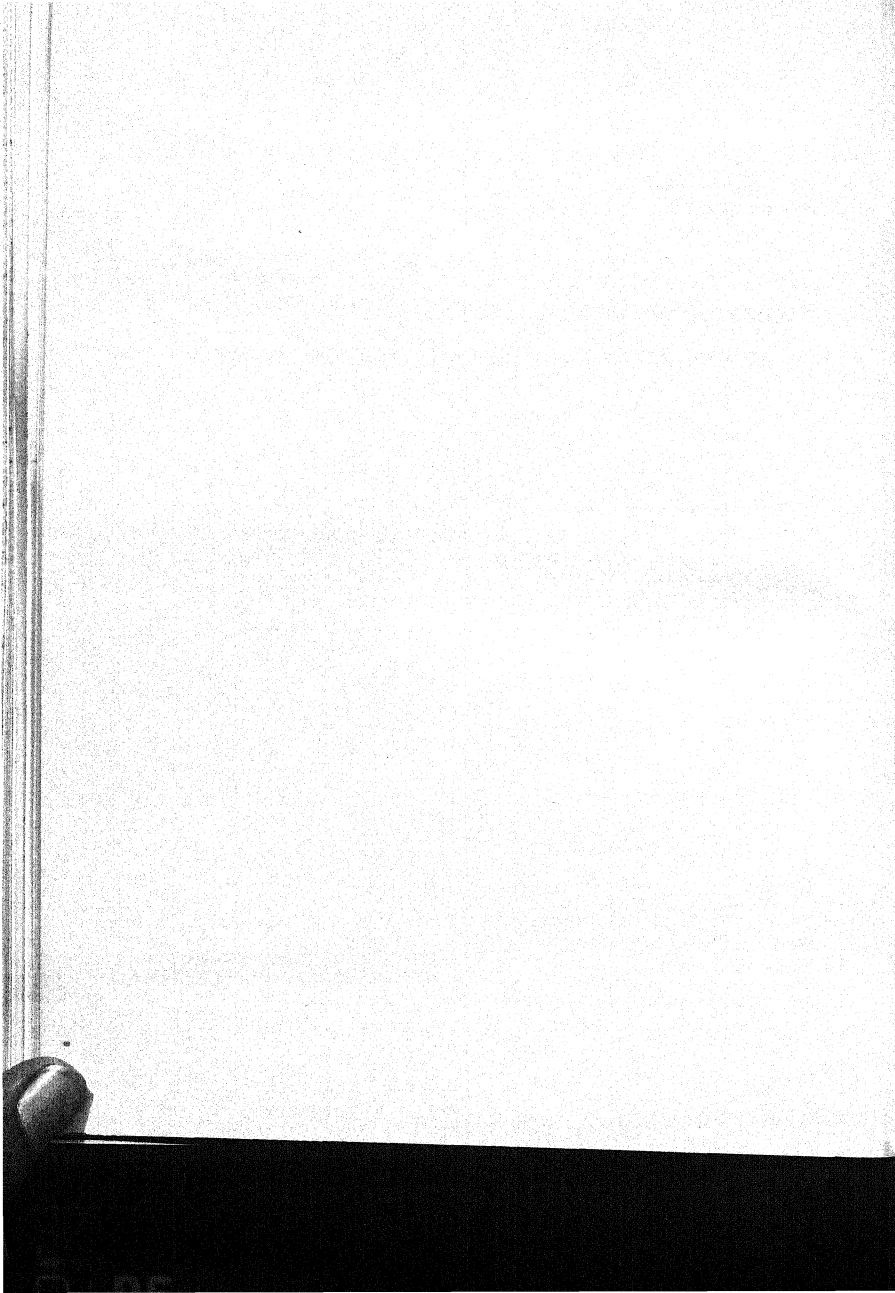
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# STUDIES IN *CAJANUS INDICUS*.

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(Received for publication on 16th May 1930.)

## I. INTRODUCTION.

Pigeon-pea (*Cajanus indicus*) ranks high amongst the pulse crops of India—entering, as it does, into the daily food of a considerable number of people. It is eaten largely in the form of split pulse as *dal*, while its tender green pods constitute a very favourite vegetable. The outer integuments of its seed together with part of the kernel provide a valuable food for milch cattle. The stalks are utilized for various purposes, such as roofing, wattling sides of carts and basket-making.

The importance of this crop in the Central Provinces and Berar can be readily understood when it is realized that roughly 492,166 acres are, every year, directly devoted to its production, while mixed with cotton and *juar* (*Andropogon Sorghum*), it covers no less than 2,008,167 acres. It is grown to a larger extent in Berar than in the Central Provinces, owing to its usefulness as a restorative rotation crop with cotton. As a pure crop, it is generally grown only on land which is considered too poor for cotton. As a mixed crop with cotton, the richer the soil, the smaller the proportion of *tur* (*Cajanus indicus*) in the mixture, while on very rich soils it is omitted altogether.

The following Table gives the distribution of area under this crop in the various districts of the Central Provinces and Berar\* :—

District	Area under <i>Tur</i> alone	Area under Cotton and <i>Tur</i>	Area under <i>Juar</i> and <i>Tur</i>
Saugor . . . . .	939	10,427	28,442
Damoh . . . . .	841	1,038	27,350
Jubbulpore . . . . .	5,000	8,768	16,744
Mandla . . . . .	979	21	3
Seoni . . . . .	1,746	14,513	9,539
Narsinghpur . . . . .	4,872	37,136	27,475
Hoshangabad . . . . .	2,185	99,573	24,190
Nimar . . . . .	16,944	163,674	1,260
Betul . . . . .	1,054	25,556	113,993
Chhindwara . . . . .	4,925	80,438	110,148
Wardha . . . . .	508	511,172	51,246
Nagpur . . . . .	13,337	351,190	166,086
Chanda . . . . .	1,218	70,233	23,616
Bhandara . . . . .	2,499	4,992	18,046
Balaghat . . . . .	1,423	20	4,273
Drug . . . . .	46,336	1,904	9
Raipur . . . . .	12,210	167	10
Bilaspur . . . . .	16,518	441	6
Total for the C. P. . . . .	138,534	1,381,263	628,436
Akola . . . . .	75,676	..	..
Amraoti . . . . .	85,645	..	..
Buldana . . . . .	56,125	..	..
Yeatmal . . . . .	136,186	..	..
Total for Berar . . . . .	353,632	..	..
Total for the C. P. & Berar . . . . .	492,166	1,381,263	628,436

\* Season and crop report of the Central Provinces and Berar for the year 1925-26.

The annual harvest at present reaches a total of 142,285 tons which, valued at the modest figure of 20 lb. to the rupee, runs approximately into Rs. 15,823,920.

## II. INVESTIGATIONS.

In the improvement of any crop the first step usually consists in the isolation and raising of pure strains. Through the help of the district officers, samples of seed of *tur* and *arhar* (*Cajanus indicus*) were obtained from the various parts of the province and grown in the Botanical area on the Government Experimental Farm, Nagpur. A close study of these samples revealed that the ordinary field crop of pigeon-pea consists of a most diverse assemblage of forms. Isolation of constant forms and their growth in pure culture was, therefore, commenced and in 1926, the crop was systematically classified into types and the work published in the annual report of that year under the title "Classification of the Types of *Cajanus indicus* grown in the Central Provinces and Berar". The next step in the investigations was to make a detailed study of the inheritance of some of the more important characters. For this purpose, hybridization on a large scale had to be resorted to. A preliminary report relating to this aspect of the study was published in the sectional report of 1927. Since that date considerable progress has been made in these investigations and much valuable information collected which will form the subject of a separate similar publication.

### A. Morphological Studies.

Belonging to the tribe Phaseoleae, sub-order Papilionaceae of the great Natural Order Leguminosae, the genus *Cajanus* includes but one species *C. indicus*, Spreng, which is commonly known as pigeon-pea, *rahar*, *arhar* or *tur*. This is an erect perennial shrub with grooved silky branches. Leaves are three-foliate. Leaflets oblong lanceolate, acute, entire, densely silky beneath and indistinctly gland-dotted. Stipules small, ovate-lanceolate with thick median nerve. Stipels filiform. Flowers borne in axillary corymbose racemes, often forming a terminal panicle. Bracts similar to stipels, caducous, Pedicels downy. Calyx tube campanulate, teeth short, each one nerved, the two upper sub-connate, the three lower spreading. Standard obovate, emarginate, shortly clawed, with two inflexed auricles at base. Wings obliquely obovate, clawed. Keel obtuse with an incurved tip. Stamens diadelphous. Ovary subsessile, few ovuled. Style long, filiform, much upcurved. Stigma capitate. Pod linear straight, narrowed at both ends, densely glandular, pilose with oblique depressions between seeds.\*

*Germination.* The seed of pigeon-pea is usually sown at the beginning of the rainy season and under suitable field conditions, the seedlings begin to appear above ground on or about the fifth day. On the second day the testa splits open near the micropyle, and the tip of the radicle elongates and emerges from the seed coat. The hypocotyl appears as an arch on the third day and continues to grow upwards.

\* Duthie, J. F. The Flora of the Upper Gangetic Plain.

When the arch has attained the height of 1 cm., the cotyledons which are folded up in a conduplicate and half-equant manner escape from the soil. The hypocotyl develops a light purple colour and straightens out in about six hours. The cotyledons now begin to increase in size, turn green and by the seventh day become fully expanded (Plate I). The plumule, which is at first concealed between the cotyledons, develops into the stem and leaves of the plant. When the seedlings are about a month old, they stand about 24 cm. from the ground. At this stage the axillary buds begin to grow and the mature cotyledons which have assumed a length of about 6 cm. begin to drop off. The first foliage leaf is generally three foliate, sometimes one or two foliate. The cotyledons bear minute stipules about 0.2 cm. in length.

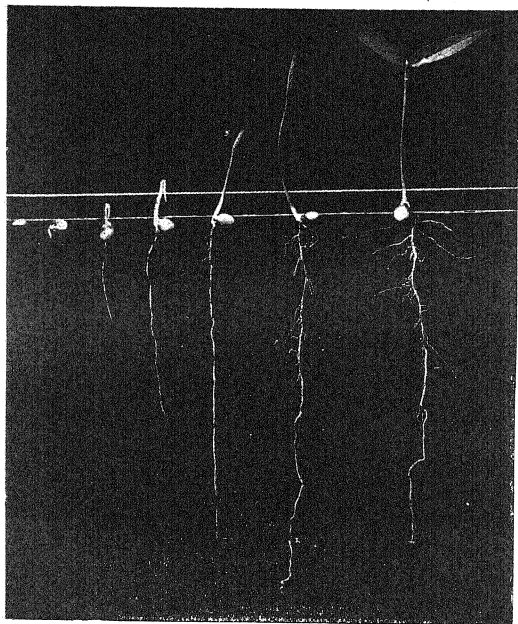
*Habit of growth.* *Tur* plants show considerable variations in height. The point on the main stem where branching begins, the number of secondary branches and the angle at which these are given off also vary. [Plates II, III, IV and IV(a).] The height, of course, must vary with the general conditions of nutrition, but under the same environment, it has been observed that, among the early ripening *turs*, Type 2 d. and Type 6 c. are definitely dwarf, while Type 13 c. is distinctly tall. For example, in 1926, when the majority of the early ripening *turs* attained a height of 140 to 150 cm., Type 2 d. and Type 6 c. measured 112 and 120 cm. respectively, while Type 13 c. was as high as 192 cm. Amongst the late ripening *arhars*, the upright forms have been found to attain a height of 210 to 230 cm. as against the spreading ones which seldom go beyond 190 or 200 cm.

In most types the branching begins from the 6th to the 10th node, i.e., 15 to 25 cm. above ground, but Type 1 b. and Type 19 do not give off their first lateral branch below the 16th node, which is usually 30 to 40 cm. from the ground. Branching in the spreading forms of the late ripening *turs* commences a little lower on the stem than in the case of the upright forms.

Variations have also been observed in the tendency of the various types to produce side shoots. While some like Types 19 and 22 throw off only a few side branches, there are others which give many vigorous side shoots.

Widest range exists in regard to the angle at which the secondary branches arise from the main stem. In the case of plants with spreading habit, the basal branches arise at an angle of 60°-70°, while in the erect forms branching takes place close to the stem at an angle of 30°-40°. Due to these variations, four different types of branching can be recognized :—

- (i) Basal branches arising at an angle of about 30° and giving an absolutely erect appearance.
- (ii) Basal branches arising at an angle of about 40° and giving an erect appearance.
- (iii) Basal branches arising at an angle of about 50° and giving a semi-erect appearance.
- (iv) Basal branches arising at an angle of about 60° and giving a spreading open appearance.



Germination stages. (1st to 7th day).



Type 13 a.



Type 1 a.



Type 19.

Branches



Type 16 b.



Type 10.

Branches

Types of branching



Type 1 b.



Type 13 c.



Type 5 b.



Type 17 b.

erect.

spreading.  
in tur.



Type 18a.



Branches erect.

Type 9 b.



Type 2 b.  
Branches semi-erect.

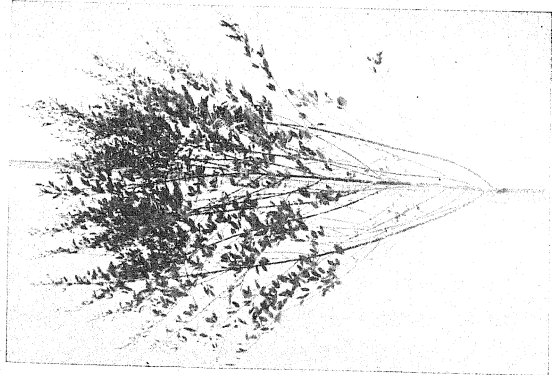


Type 11 b.

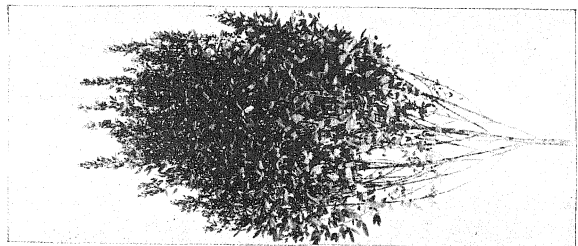
Branches spreading.



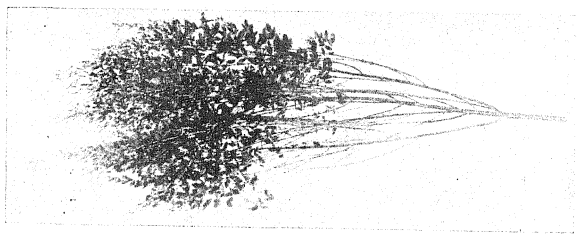
Type 6 c.



Type 21.



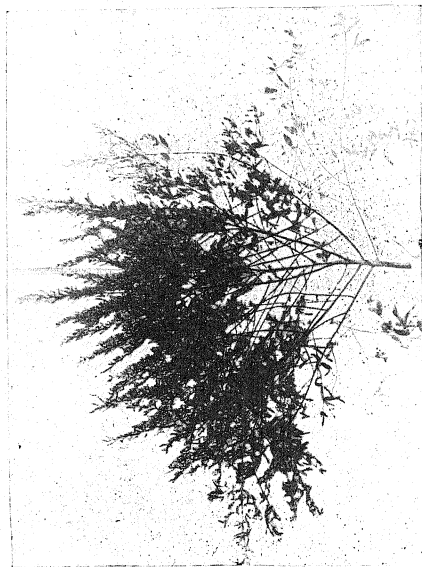
Type 31.  
Types of branching in *arbores.*



Type 26.

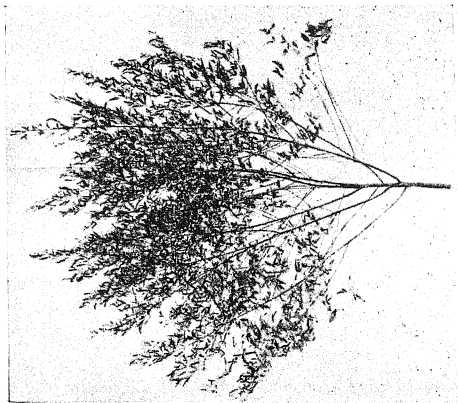


Type 22.



Type 24,

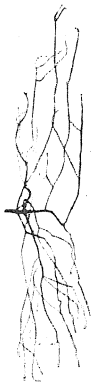
Types of branching in *arhar*.



Type 25.



Type 1 b.



Type 13 a.



Type 16 b.



Type 22.

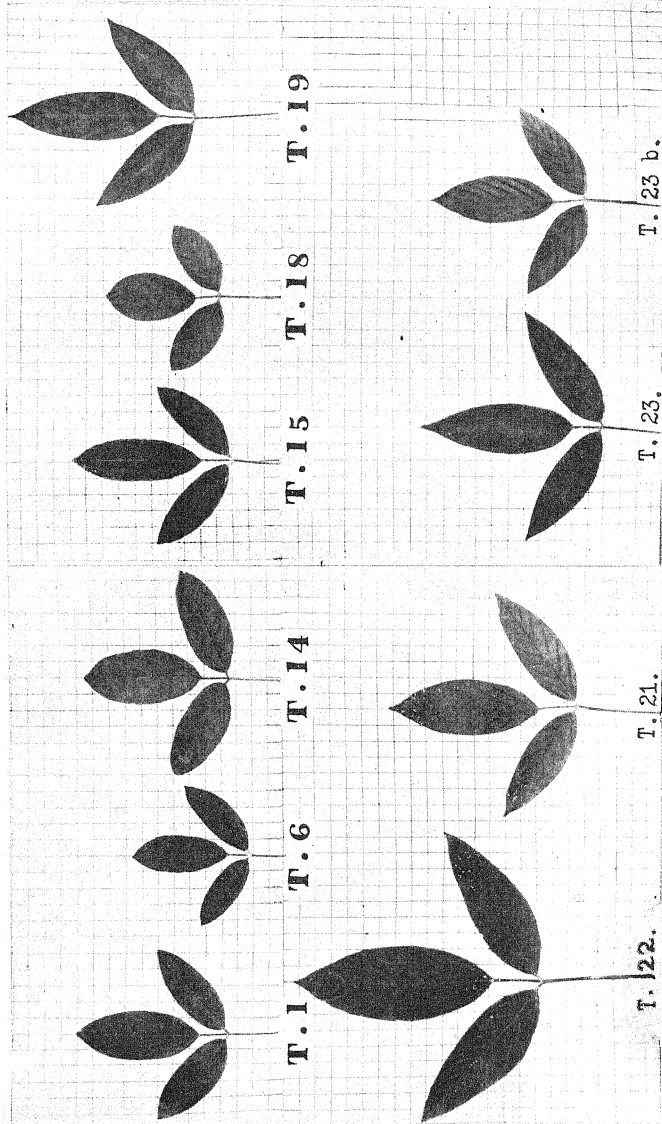


Type 28.



Type 24.

Root systems of *cojonus indica*.



Types of leaves in *Coffea indica*.

**Root system.** The root system appears to be closely related to the habit of growth. The lateral roots are much longer in the spreading types than in the erect forms. But Types 19 and 22 possess sparse root system, while in the case of Type 1 b. short rootlets have been observed to arise at an acute angle near the surface of the ground. (Plate V).

**Leaves** The total length of the leaf, as also the size, shape and texture of the leaflets, differ in the various types. (Plate VI.) Differences also exist in the tone of colour of foliage. Among the early ripening *turs*, Type 19 possesses the longest leaves—17 cm., and Type 2 d., Type 3 d. and Type 6 c., the shortest—9 to 10 cm. only. In most of the other types, the leaves are 11-14 cm. long, their rachis 2-4 to 4 cm.; blade of the terminal leaflet 6 to 8 cm./2-3 to 3-4 cm.; rachilla 1-2 cm.; right leaflet 6-5/ 2-5 cm.; the left leaflet 0-3 cm. larger than the right, its rachilla 0-3 cm. In Type 19, the main stalk is 4 cm.; the terminal leaf blade 10-3/ 3-3 cm. and rachilla 2-2 cm. Rachis in the case of Type 3 d. is very short, while the terminal leaflet in Type 18 a. is very broad. Type 14 and Type 13a. possess rather coarse leaves. In Type 11 a. the terminal leaflet is deflected at the joint, its midrib curved and the leaflet much raised. The colour of leaves in the case of Type 1 b., Type 2 b., Type 17 b., Type 18 a. and Type 19 is dark green. Among the late ripening *turs*, Type 22 possesses very large leaves—23 cm.; while Type 23 b. has only small leaves. In most of the other types, the leaves measure 13 to 15½ cm. In Type 23 the leaflets are broadest at the base and taper sharply at the apex; the terminal leaflet is deflected at the joint and its midrib is much curved, raising it above the level of the other leaflets.

**Flowers.** The flowers are borne on corymbs about 2-5 to 3 cm. long when the lowest flower opens. After this the inflorescence elongates into a raceme 4-9 cm. The inflorescence varies from the elongated form in Type 9 b., Type 10, Type 17 b. and Type 19, by every gradation to the short forms in Type 3 d., Type 6 c., Type 11 a. and Type 22. The length of the peduncle in the elongated forms varies from 7 to 10 cm. and in the short ones from 3 to 4-5 cm. In the late ripening *arhars*, the flowers are more or less grouped together at the end of the branches. In the early *turs* they are distributed along the branches. Usually two flowers open at a time on the same inflorescence, but the process of flowering continues in each plant almost up to the time of harvest. The various types show great difference in the length of their growing period as well as in the time at which they start flowering. For instance, the early ripening *turs* of Nagpur and Berar are ready for harvesting in December, while the late *arhars* in the north of the Province do not ripen until the end of March. Among *turs* very early types start to flower in the last week of September; early types in the first and second week of October; medium types in the third week, and the late types in the 4th week of October or even later. The *arhar* plants start to flower after the first week of November.

With the exception of Types 19 and 22, which possess large flowers, there is but slight difference in the size of flowers of the other types. The length of flower

ranges from 2.4 to 2.9 cm., pedicles are 0.7 to 1.2 cm., calyx 0.7 to 0.9 cm./0.3 to 0.4 cm., teeth 0.2 to 0.3 cm., standard 1.6 to 1.9 cm./1.4 to 1.8 cm. and claw 0.3 cm.

Flowers in Type 19 are 3 cm. long, their pedicles 1 cm., calyx 1.1 (tube 0.6 cm., teeth 0.5 cm.); Standard 2.0/1.8 cm.; wings 1.6/0.7 cm., keel 1.6/0.5 cm., stamens 1.5 cm., and ovary 0.45/0.15 cm.

The colour of the flower is very distinct and constitutes the chief distinguishing feature in the types. (Plate VII.) The flowers may be:—

- (1) Pale yellow, back of standard with self-coloured veins.
- (2) Pale yellow, back of standard veined with red.
- (3) Yellow, back of standard with self-coloured veins.
- (4) Yellow, back of standard veined with red.
- (5) Yellow, back of standard with deep purple veins purple spreading between veins in lower half of standard.
- (6) Orange yellow.
- (7) Yellow, back of standard purple.

*Pods.* The pods vary in size, width and the nature of the markings. They are very large in Type 22 (10 cm.) and small in Type 13 c. (5.5 cm.). In other types the length varies from 6.5 to 8 cm., width from 0.6 to 0.9 cm. and the stalk from 1 to 1.5 cm. Pods in Type 19 are very broad (1.2 cm.) and pendent, with their tips pointing downwards, while in Type 13 c. they are quite erect. The pods may be:—

- (i) Green.
- (ii) Green blotched with maroon or
- (iii) Dark (Plate VIII).

*Seeds.* The seeds differ in respect of size, shape and colour of the seed-coat. From the point of view of size, four grades have been distinguished and have been described as very large, large, medium and small. (Plate IX.) Differences also exist in the shape of the seed which may be round, oval, kidney-shaped, or slightly rectangular. (Plate IX.) But for each type, the size, shape and colour are constant. The colour of the seed-coat may be:—

- (1) Dirty white to distinctly white.
- (2) Light brown to chestnut brown.
- (3) Dark mottled brown, and
- (4) Purplish black.

(Plate IX.)

In white seeds a spot occurs on the micropyle the colour of which varies from light brown to dark brown. In certain seeds two prominent ridges may be noted on the hilum.



# DESCRIPTION OF PLATE VII.

Fig. 1. Flowers pale yellow, back of standard with self coloured veins.

Fig. 2. Flowers pale yellow, back of standard veined with red.

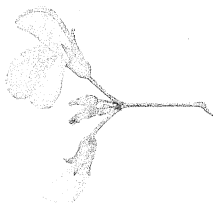
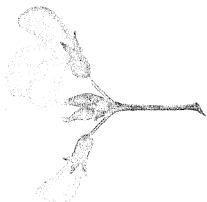
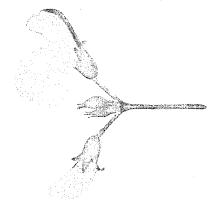
Fig. 3. Flowers yellow, back of standard with self coloured veins.

Fig. 4. Flowers yellow, back of standard veined with red.

Fig. 5. Flowers yellow, back of standard with deep purple veins, purple spreading between veins in lower half of standard.

Fig. 6. Flowers orange yellow.

Fig. 7. Flowers yellow, back of standard purple.

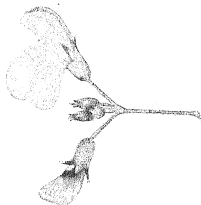
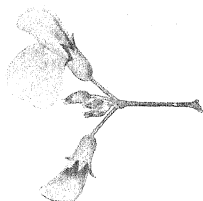
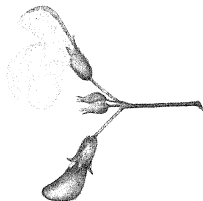


4

3

2

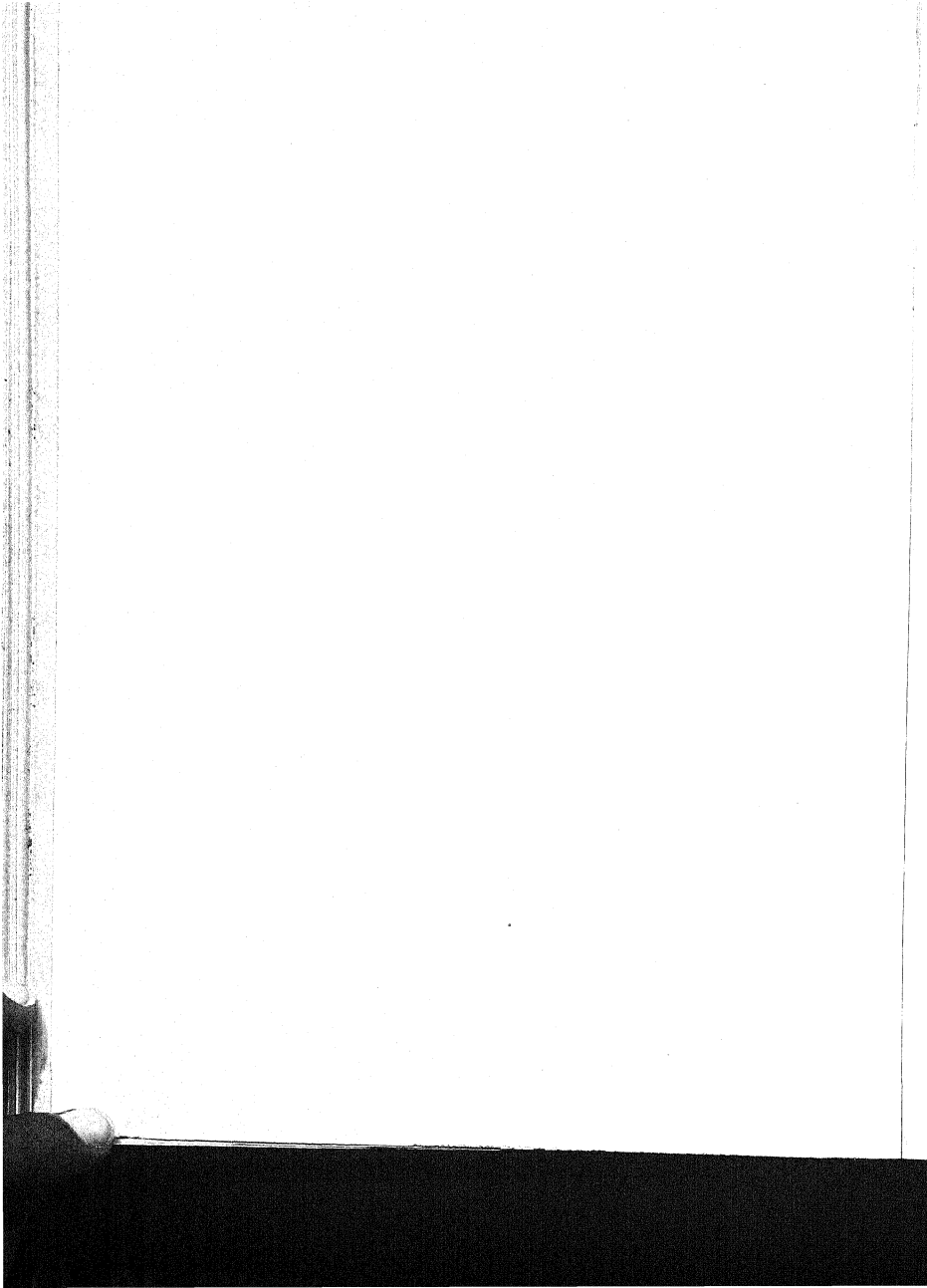
1

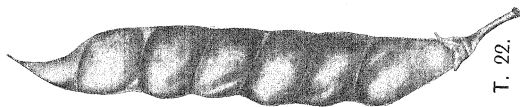


7

6

5





T. 22.

Green.



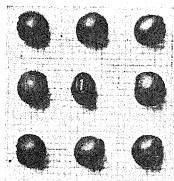
T. 19.

Blotched with maroon.



Dark.

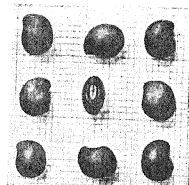
PODS OF CAJANUS INDICUS. (NATURAL SIZE.)



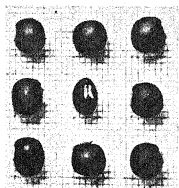
Type 20.



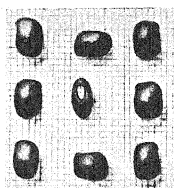
Type 13 c.



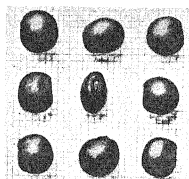
Type 16 a.



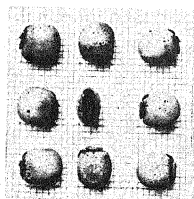
Type 13 b.



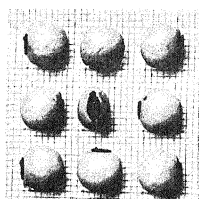
Type 4 a.



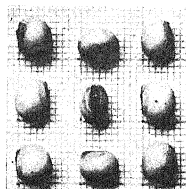
Type 31.



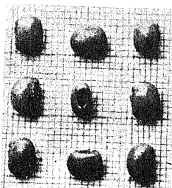
Type 19.



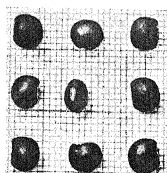
Type 22.



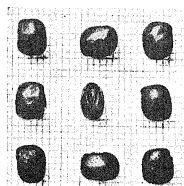
Type 21.



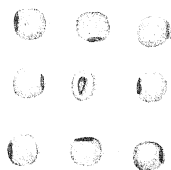
Type 1 b.



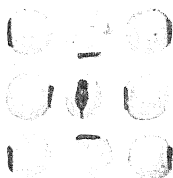
Type 17.



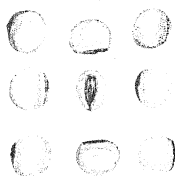
Type 27.



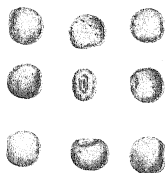
Type 1 a.  
Dull white.



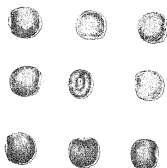
Type 22.  
White.



Type 21.  
Distinctly white.



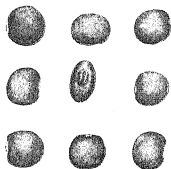
Type 2 b.  
Light brown.



Type 20.  
Brown.



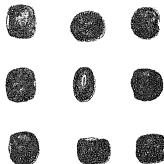
Type 18.  
Dark brown



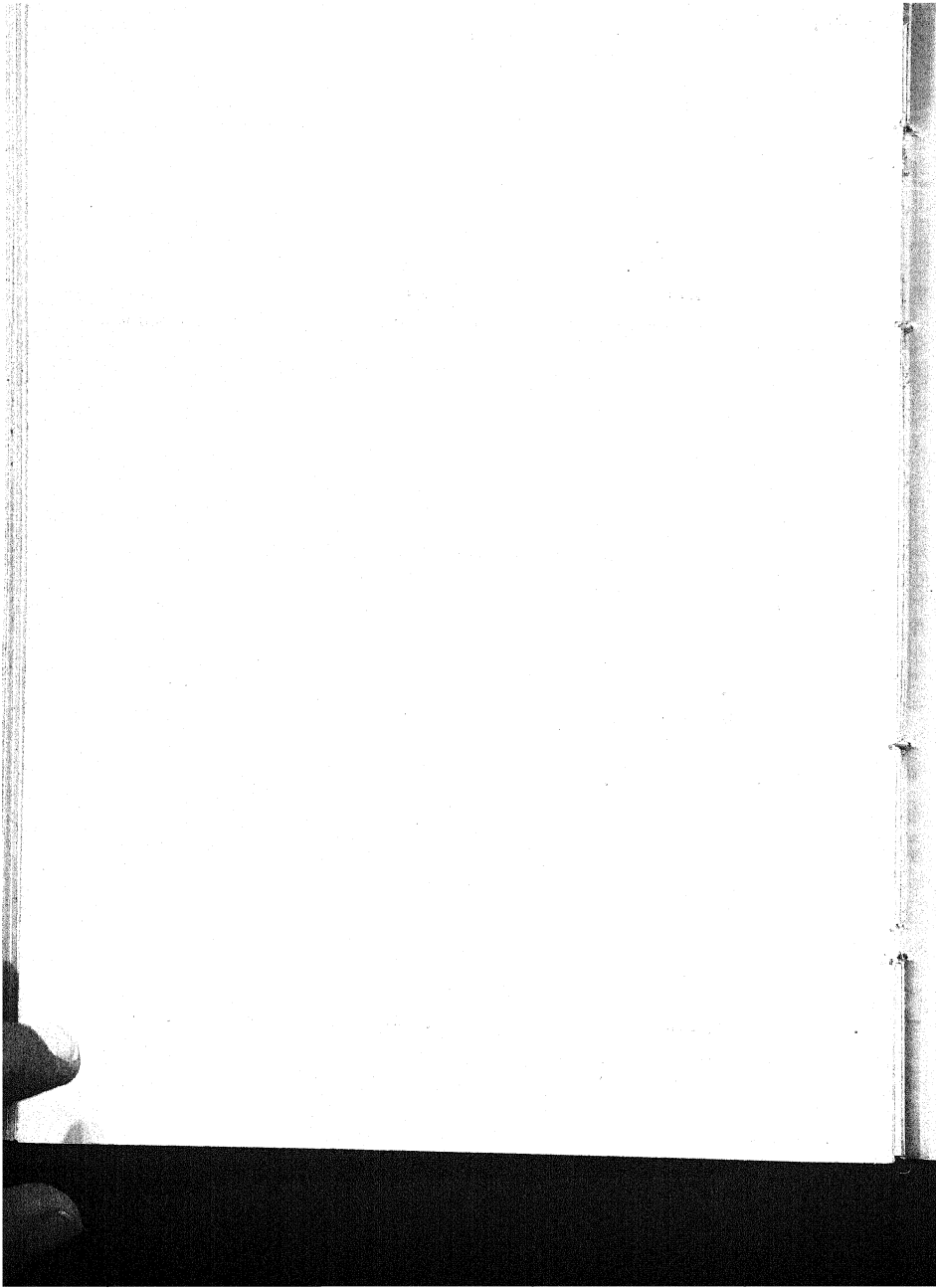
Type 31.  
Chestnut brown.



Type 17.  
Purplish black.



Type 27.  
Dark mottled brown



*B. Flowering, Pollination and Natural Cross-fertilization.*

Our study of the flowering, pollination and cross-fertilization in this crop has, generally speaking, yielded results similar to those obtained and described by the Howards.<sup>1</sup>

*Flowering.* Certain variations have been observed in regard to the duration of the opening of flowers at Nagpur. Towards the end of November 1925, observations were recorded on the opening and closing of 238 flowers. Buds which were likely to open the following day were labelled in the evening and the investigations were continued until dusk the next day. The results obtained are tabulated below :—

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<sup>1</sup> Studies in the Pollination of Indian crops. *Mem. Dept. Agri. India, Bot. Ser.*, Vol. X, No. 5, 1920.

9 to 10			10-5 to 11			11-5 to 12			12-5 to 1			1-5 to 2		
Time of opening	Time of closing	Duration	Time of opening	Time of closing	Duration	Time of opening	Time of closing	Duration	Time of opening	Time of closing	Duration	Time of opening	Time of closing	Duration
9-5	1-25	4-20	10-30	12-30	2-0	11-15	1-20	2-5	12-10	1-20	1-10	1-15	2-10	0-55
9-20	12-30	3-10	10-45	2-40	3-55	11-20	2-0	2-40	12-15	3-55	3-20	1-15	3-40	2-25
9-30	11-0	1-30	10-55	3-45	4-50	11-20	2-0	2-40	12-20	3-30	3-10	1-15	3-40	2-25
10-0	3-45	5-45	11-0	1-55	2-55	11-25	12-45	1-20	12-30	3-45	3-15	1-15	3-40	2-25
..	..	..	11-0	2-50	3-50	11-25	2-10	2-45	12-30	4-25	3-55	1-20	3-45	2-25
..	..	..	..	..	..	11-25	2-50	3-25	12-45	3-0	2-15	1-20	4-20	3-0
..	..	..	..	..	..	11-25	2-55	3-30	12-45	3-15	2-30	1-30	3-50	2-20
..	..	..	..	..	..	11-25	3-0	3-35	12-45	3-15	2-30	1-30	4-15	2-45
..	..	..	..	..	..	11-40	2-0	2-20	12-45	3-20	2-35	1-30	4-15	2-45
..	..	..	..	..	..	11-40	2-0	2-20	12-45	4-0	3-15	1-30	5-0	3-30
..	..	..	..	..	..	11-40	2-0	2-20	12-45	4-0	3-15	1-30	5-0	3-30
..	..	..	..	..	..	11-50	2-0	2-20	12-45	4-15	3-30	1-30	5-0	3-30
..	..	..	..	..	..	11-50	2-50	3-0	1-0	2-15	1-15	1-40	5-0	2-10
..	..	..	..	..	..	11-50	3-0	3-10	1-0	2-35	1-35	1-40	4-30	2-50
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..	..	..	..	..	..	11-55	2-0	2-5	1-0	2-40	1-40	1-40	5-0	3-20
..	..	..	..	..	..	11-55	2-0	2-5	1-0	2-45	1-45	1-40	5-30	3-50
..	..	..	..	..	..	11-55	2-10	2-10	1-0	2-45	1-45	1-40	5-30	3-50
..	..	..	..	..	..	11-55	2-15	2-20	1-0	2-45	1-45	1-45	4-0	2-15
..	..	..	..	..	..	11-55	4-25	4-30	1-0	3-10	2-10	1-45	4-0	2-15
..	..	..	..	..	..	12-0	2-0	2-0	1-0	3-10	2-10	1-45	4-0	2-15
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..	..	..	..	..	..	12-0	2-0	2-0	1-0	3-15	2-15	1-50	3-35	1-45
..	..	..	..	..	..	12-0	2-0	2-0	1-0	3-15	2-15	1-50	4-0	2-10
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..	..	..	..	..	..	12-0	4-0	4-0	1-0	3-25	2-25	1-50	4-40	2-50
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..	..	..	..	..	..	..	..	..	1-0	3-25	2-25	1-50	4-40	2-50
..	..	..	..	..	..	..	..	..	1-0	3-30	2-30	2-0	4-45	2-45
..	..	..	..	..	..	..	..	..	1-0	3-30	2-30	2-0	4-45	2-45
..	..	..	..	..	..	..	..	..	1-0	3-30	2-30	2-0	4-45	2-45
..	..	..	..	..	..	..	..	..	1-0	3-30	2-30	2-0	4-45	2-45
..	..	..	..	..	..	..	..	..	1-0	4-0	3-0	..	..	..
..	..	..	..	..	..	..	..	..	1-0	4-0	3-0	..	..	..
..	..	..	..	..	..	..	..	..	1-0	4-10	3-10	..	..	..
..	..	..	..	..	..	..	..	..	1-0	4-15	3-15	..	..	..
..	..	..	..	..	..	..	..	..	1-0	4-30	3-30	..	..	..

[illegible]

It will be seen that 4 flowers opened between 9 and 10 A.M.; 5 between 10-5 and 11 A.M.; 27 between 11-5 and 12 noon; 41 between 12-5 and 1 P.M.; 35 between 1-5 and 2 P.M.; 47 between 2-5 and 3 P.M.; 21 between 3-5 and 4 P.M.; 7 between 4-5 and 5 P.M.; and 4 between 5-5 and 6 P.M. 24 flowers were cleistogamic and some of these produced fully developed pods. 5 flowers opened partially and then closed; while 15 buds dried up or were damaged by blister beetles.

Of the 191 buds which opened into flowers, 170 closed the same day. Observations on similar lines made on the 13th November, 1926 showed that out of 571 flowers, which opened, 492 closed the same day. Thus, it is obvious that while the duration of opening may be as long as a day and a half at Pusa, at Nagpur it does not exceed 6 hours. A few flowers, which opened at about 4 P.M. or after, remained open throughout the night and closed before noon the following day. The duration of opening of flowers which were bagged with paraffin paper or which were under muslin bags, however, was observed to be similar to that at Pusa. Out of 230 flowers which opened under bags, only 14 closed the same day, while 216 remained open throughout the night. Under muslin bags the flowers were noticed to start opening about 10 minutes earlier than was the case with unbagged plants.

The following Table gives the duration of flowers in unbagged plants :—

No. of flowers	Duration of opening
3	35 minutes to 1 hour.
8	1 hour 5 minutes to 1 hour 30 minutes.
21	1 hour 35 minutes to 2 hours.
46	2 hours 5 minutes to 2 hours 30 minutes.
29	2 hours 35 minutes to 3 hours.
18	3 hours 5 minutes to 3 hours 30 minutes.
7	3 hours 35 minutes to 4 hours.
2	4 hours 5 minutes to 4 hours 30 minutes.
1	4 hours 35 minutes to 5 hours.
0	5 hours 5 minutes to 5 hours 30 minutes.
1	5 hours 35 minutes to 6 hours.
3	17 hours.
3	18 hours.
4	19 hours.
5	20 hours.
5	21 hours.
2	22 hours.

**Pollination.** In young buds the stigma lies above the level of the anthers and the style is so curved at the tip that the stigmatic surface is directed towards the anthers which are arranged around the style in two groups, five above and five below. With the development of the bud, the filaments elongate bringing the top five anthers to the level of the stigma. This stage is completed before the bursting of the anthers, which occurs in the bud a day before the flower opens. In spite of the fact that the stigma is completely covered with the pollen of the same flower, self-fertilization is not the rule in this crop. *Megachile lanata* and *Apis florea* visit every open flower and bring about cross-fertilization. *Megachile lanata* grasps the wing with its middle and hind pair of legs, presses its head forcibly against the standard and sucks the honey from the flower. The wings and keel of the flower are pressed downwards and the pistil and stamens project from the keel and rub against its body as they pass between the abdomen and one of the hind pair of legs. The bee also collects pollen adhering to the anthers and departs, when the stamens and pistil return to their former position. *Megachile lanata* has also been noticed to open the buds which are about to flower. The small bee, *Apis florea*, has a habit of alighting on the wings of the flower and getting at the pollen by separating the upper edges of the keel petals by holding one keel petal by the legs and pushing the other by the head. A few flowers are also visited by the large black bee. Such flowers are easily recognisable as the insect is too heavy and the stamens and pistil do not retreat to their former position for a considerable time after the departure of the visitor.

In our hybridization work for the study of the inheritance of certain characters in *Cajanus indicus*, it has been observed that the emasculation of buds, which are likely to open the following morning, cannot be carried out after 10 A.M. as at this time the anthers begin to burst.

To ascertain the exact time of bursting of anthers, a number of developed buds likely to open the following day were examined. The overlapping margins of vexillum were carefully loosened, and the keel petals slightly slit open at the apex to render easy examination by means of a lens. Out of 74 buds in which the anthers were found to have just burst, 32 flowered the next day as will be seen from the following Table :—



## STUDIES IN CAJANUS INDICUS

[illegible]

Rainy conditions appear to have a marked influence on the setting of seed in this crop. In order to determine the percentage of setting on rainy days, 270 flowers were marked on the 14th of October 1925. Rain started at 11-30 A.M. and continued till 4 P.M. During this period there was no sun-shine recorded. The maximum temperature was 86.1, the minimum 71.0 and the rainfall amounted to 1.58 inches. It was found that out of the 270 flowers thus marked, only 46 formed pods. The percentage of setting was therefore 17. Under muslin bags the percentage of setting on cloudy days was found to be only 13. The following Table shows the results obtained in our investigations on the setting of seed under different conditions on sunny days:—

Date	Type	Flowers		Flowers		Flowers		Flowers	
		Crossed	Set	Selfed	Set	Bagged	Set	Unbagged	Set
24th December 1925	21	25	13	25	13	50	27	25	19
21st December 1925	22	41	33	..	..	108	52	100	54
30th December 1925	30	25	4	28	9	25	12	25	6
20th December 1926	32	27	4	23	7	25	10	25	11
28th December 1926	33	25	13	20	9	50	23	25	15
27th December 1926	34	25	7	33	15	25	3	25	17
26th December 1926	35	45	17	15	3	25	14	25	13
25th December 1926	35	20	10	18	13	50	31	50	37
Total		242	110	162	69	358	172	300	172
Percentage of setting		45		42		48		57	

**Natural cross-fertilization.** Considerable amount of cross-fertilization has been observed to take place in *Cajanus indicus*. The detection of heterozygous individual is rendered easy if the parent plants used in the determination of the percentage of natural crossing possess recessive characters, such as yellow flowers, green pods or white seeds. If plants possessing such characters are selected from a field and the seed of each plant sown separately, a large amount of splitting will be detected in the progeny.

In our investigations, seed of 51 single plants of early ripening *tura*, possessing yellow flowers, with back of standard without red veins, was sown separately and the progeny examined. 38 rows or 74 per cent showed splitting into yellow flowered plants and plants with back of standard veined with red. Similar splitting in flower colour was recorded in 58 per cent. of the line cultures raised in a second set of

experiments. The rows grown from single plants possessing green pods segregated in the following manner :—

Parent plant		Progeny		
		Total No. of plants	Plants with green pods	Plants with lined pods
No. 15 . . . . .	With green pods	41	32	9
„ 21 . . . . .	Ditto	45	24	21
„ 34 . . . . .	Ditto	45	37	8
„ 42 . . . . .	Ditto	54	49	6
„ 47 . . . . .	Ditto	40	18	22
„ 49 . . . . .	Ditto	14	9	5
„ 79 . . . . .	Ditto	34	25	9
„ 87 . . . . .	Ditto	61	56	5
„ 144 . . . . .	Ditto	20	18	2

In order to determine the extent to which natural cross-fertilization occurs in this crop, types possessing different pairs of contrasting characters were grown in adjacent rows in 1927. 116 plants were allowed to seed without being bagged and the seed of each of these plants was sown separately. Examination of the progeny in the subsequent generation gave results as shown in the following Tables :—

Line number	No. 49 with green pods grown next to No. 13 with dark pods			No. 108 with green pods grown next to No. 80 with lined pods			No. 15 with green pods grown next to No. 14 with dark pods			No. 144 with green pods grown next to No. 114 with lined pods		
	Total number of plants in the line	Homozygotes	Heterozygotes	Per cent of heterozygotes	Total number of plants in the line	Homozygotes	Heterozygotes	Per cent of heterozygotes	Total number of plants in the line	Total number of plants in the line	Homozygotes	Per cent of heterozygotes
1	282	156	106	40	187	126	61	33	224	197	27	12
2	119	83	36	30	166	134	22	14	105	95	13	11
3	194	172	22	11	186	162	24	18	110	98	12	11
4	87	58	29	33	111	78	33	30	90	84	6	7
5	108	56	52	48	136	128	4	6	94	82	12	13
6	86	62	24	28	180	147	33	18	58	46	12	21
7	..	..	..	..	79	60	19	24	134	109	25	19
8	..	..	..	..	122	106	17	14	187	170	17	9
9	..	..	..	..	65	52	13	20	136	162	24	13
10	..	..	..	..	131	92	21	17	118	108	10	8

Average percentage of heterozygotes = 14.

## STUDIES IN CAJANUS INDICUS

Line number	No. 47 with white seed grown next to No. 50 with brown seed				No. 148 with white seed grown next to No. 19 with brown seed				No. 8 with white seed grown next to No. 146 with brown seed				No. 6 with white seed grown next to No. 20 with brown seed			
	Total number plants	Homo-zygotes	Hetero-zygotes	Per cent of hetero-zygotes	Total number plants	Homo-zygotes	Hetero-zygotes	Per cent of hetero-zygotes	Total number plants	Homo-zygotes	Hetero-zygotes	Per cent of hetero-zygotes	Total number plants	Homo-zygotes	Hetero-zygotes	Per cent of hetero-zygotes
1	97	87	10	10	184	160	24	13	197	187	10	5	245	238	7	3
2	211	214	47	18	201	195	6	3	280	256	24	12	221	213	8	3
3	110	84	26	24	170	157	13	8	381	307	54	15	216	198	18	8
4	179	156	23	13	201	195	6	3	246	219	27	11	252	240	12	5
5	133	121	12	9	485	404	31	7	323	278	45	14	269	280	19	6
6	186	157	29	16	228	217	11	5	191	168	23	12	170	160	10	6
7	121	105	16	13	223	217	16	7	267	239	28	10	209	202	7	3
8	226	180	46	20	207	187	20	10	244	221	23	9	310	292	18	6
9	346	279	67	19	168	155	13	8	187	170	17	9	207	192	15	7
10	156	132	24	15	260	230	30	12	271	246	25	9	261	240	21	8

Average percentage of heterozygotes = 13.

Line number	No. 82 with white seed grown next to No. 22 with brown seed				No. 90 with white seed grown next to No. 40 with brown seed				No. 98 with white seed grown next to No. 20 with brown seed				No. 37 with brown seed grown next to No. 332 with purple seed			
	Total number of plants	Homozygotes	Heterozygotes	Per cent. of heterozygotes	Total number of plants	Homozygotes	Heterozygotes	Per cent. of heterozygotes	Total number of plants	Homozygotes	Heterozygotes	Per cent. of heterozygotes	Total number of plants	Homozygotes	Heterozygotes	Per cent. of heterozygotes
1	239	186	50	21	303	275	28	9	206	238	28	11	218	199	19	9
2	297	225	72	24	51	48	3	6	210	194	16	8	209	174	36	17
3	249	170	70	29	82	70	12	15	363	320	33	9	176	156	20	11
4	255	226	59	21	110	99	11	10	152	134	18	12	150	126	24	16
5	199	140	50	25	100	175	24	12	300	246	63	20	122	101	21	17
6	237	180	57	24	124	100	24	19	389	356	33	8	210	182	28	11
7	124	100	24	19	297	223	44	16	326	285	41	13	183	116	67	16
8	157	137	30	16	137	116	21	15	350	320	30	11	150	140	10	6
9	228	159	69	30	101	109	22	12	325	284	41	13	291	219	72	25
10	341	237	114	33	150	134	16	11	282	261	21	7	238	197	38	16

Average percentage of heterozygotes = 13.

It will be seen that every row shows splitting and that the percentage of heterozygous individuals amounts to 14 and 13 when pod and seed characters are taken into account respectively.

At the same time two of our types—Type 1 and Type 20—were sown in quarter acre adjacent blocks. Type 1 possesses green pods with white seed and Type 20, lined pods with red seed. 119 single plants possessing white seed were selected from the first plot and grown separately in rows the next year. 96 rows showed splitting. The total number of plants in these 96 rows was 6,295 out of which 5,953 plants were found to be white seeded and 342 red seeded. The percentage of heterozygotes was therefore 5.

Out of the 144 rows raised from plants with green pods, 94 showed splitting. The total number of plants in these 94 rows was 5,171, out of which 5,004 plants were found to possess green pods, while 167 had lined pods. The percentage of heterozygotes was therefore 3.

In addition to the above, 60 white seeded single plants were selected from a cultivator's field at Nagpur. His crop consisted largely of white seeded *tur* but all the three types of pods were met with. Of these 60 plants, 33 possessed green pods. Examination of the progeny raised from these 60 plants, however, showed a considerable amount of splitting. 24 rows containing an aggregate of 1,544 plants gave 1,498 plants possessing white and 46 plants possessing red seeds. The percentage of heterozygous individuals was thus 3. Again, of the 33 rows—the progeny of plants possessing green pods—28 showed splitting into plants possessing green, blotched and dark pods. The percentage of heterozygotes was thus 14.

#### C. Classification.

There are several references to the occurrence in India of two forms of *Cajanus indicus*. For example, Cook in the Flora of Bombay Presidency states that there are two varieties, one (*C. flavus*) with the standard wholly yellow and the other (*C. bicolor*) in which it is veined with red. The existence of two varieties, with yellow standard (*C. flavus*) or veined with red (*C. bicolor*) is also noted by Hooker, Gammie and Duthie. Krauss (University of Hawaii) refers to *Cajanus indicus* as consisting of one variable species subdivided into *C. flavus* which has yellow flowers and self coloured seeds and pods, the latter glabrous, and *C. bicolor*, yellow flowered with back of standard red, seeds speckled, pods blotched with maroon, and surface pubescent.

In the Central Provinces, there are certainly two distinct forms of *Cajanus indicus* but the distinguishing features of these are not those noted by the authors quoted above. The two forms met with in these provinces can be readily distinguished in the field. The first is a short, early ripening variety, generally known as *tur* and the second, a tall, late ripening variety, commonly referred to as *arhar*. Our investigations lead us to believe that any distinction between the two varieties based on flower or pod colour cannot be accurate, as same flower and pod colours are met with in both the varieties.

*Key to the types of Cajanus indicus.*I. Early Ripening. (*Thr.*)

## 1. Flowers pale yellow, back of standard with self coloured veins.

## A. Pods green.

## i. Seed white. Type 1.

(a) Branches erect . . . . . Medium in flowering.

(b) Branches erect arising very high on the stem . . . . . Early in flowering.

(c) Branches spreading . . . . . Medium in flowering.

## ii. Seed brown. Type 2.

(a) Branches erect . . . . . \* Early in flowering.

(b) Branches semi-erect . . . . . † Medium in flowering

(c) Branches spreading . . . . . Early in flowering.

(d) Dwarf branches spreading . . . . . \* Early in flowering.

(e) Branches spreading . . . . . † Medium in flowering.

(f) Dwarf branches spreading . . . . . Medium in flowering.

## B. Pods green blotched with maroon.

## i. Seed white. Type 3.

(a) Branches erect . . . . . \* Early in flowering.

(b) Branches erect sparse like T. 19 . . . . . † Medium in flowering

(c) Branches spreading . . . . . Early in flowering.

(d) Branches spreading . . . . . \* Early in flowering.

(e) Branches spreading . . . . . † Medium in flowering.

(f) Branches spreading. Plants very short . . . . . Early.

## ii. Seed brown. Type 4.

(a) Branches erect . . . . . \* Medium in flowering

(b) Branches erect . . . . . † Late in flowering.

(c) Branches spreading . . . . . \* Early in flowering.

(d) Branches spreading . . . . . † Medium in flowering.

## C. Pods dark.

## i. Seed white. Type 5.

(a) Branches erect . . . . . Medium in flowering.

(b) Branches spreading . . . . . Medium in flowering.

## ii. Seed brown. Type 6.

(a) Branches erect . . . . . Early in flowering.

(b) Branches spreading . . . . . Early in flowering.

(c) Branches very spreading Dwarf . . . . . Early in flowering.

## 2. Flowers pale yellow, back of standard veined with red.

## A. Pods green.

## Seed brown. Type 7.

Branches spreading . . . . . Early in flowering.

## B. Pods green blotched with maroon.

## i. Seed white. Type 8.

(a) Branches erect . . . . . Medium in flowering.

(b) Branches spreading . . . . . Medium in flowering.

## ii. Seed brown. Type 9.

(a) Branches erect . . . . . \* Early in flowering.

(b) Branches erect . . . . . † Medium in flowering.

(c) Branches erect . . . . . † Late in flowering.

(d) Branches erect arising high on the stem. Plants

(e) robust . . . . . Medium in flowering.

(f) Branches spreading . . . . . \* Medium in flowering

(g) Branches spreading . . . . . † Late in flowering.

- C. Pods dark.  
 Seed brown. Type 10.  
 Branches spreading . . . . . Medium in flowering.
3. Flowers yellow, back of standard with self coloured veins.  
 Pods green blotched with maroon.  
 i. Seed white. Type 11.  
 (a) Branches erect . . . . . \* Early in flowering.  
 † Medium in flowering.  
 (b) Branches spreading . . . . . Late in flowering.
- ii. Seed brown. Type 12.  
 (a) Branches erect . . . . . Medium in flowering.  
 (b) Branches spreading . . . . . Medium in flowering.
4. Flowers yellow, back of standard veined with red.  
 A. Pods green blotched with maroon.  
 Seed brown. Type 13.  
 (a) Branches very erect . . . . . Medium in flowering.  
 (b) Branches erect . . . . . \* Early in flowering.  
 † Medium in flowering.  
 (c) Branches erect very tall . . . . . Late in flowering.  
 (d) Branches spreading . . . . . \* Medium in flowering.  
 † Late in flowering.
- B. Pods dark.  
 Seed brown. Type 14.  
 Branches erect . . . . . \* Medium in flowering.  
 † Late in flowering.
5. Flowers yellow, back of standard with deep purple veins, purple spreading between veins in lower half of standard.  
 Pods green.  
 i. Seed white. Type 15.  
 Branches erect, sparse . . . . . Early in flowering.
- ii. Seed brown. Type 16.  
 (a) Branches erect . . . . . \* Medium in flowering.  
 † Late in flowering.  
 (b) Branches spreading . . . . . Medium in flowering.
6. Flowers orange yellow.  
 A. Pods green blotched with maroon.  
 Seed purplish black. Type 17.  
 (a) Branches erect . . . . . Medium in flowering.  
 (b) Branches spreading . . . . . Medium in flowering.
- B. Pods dark.  
 Seed purplish black. Type 18.  
 (a) Branches erect . . . . . Early in flowering.  
 (b) Branches spreading . . . . . Early in flowering.
7. Flowers yellow, back of standard purple.  
 Pods green blotched with maroon.  
 i. Seed white. Type 19.  
 Branches erect sparse . . . . . Early in flowering.
- ii. Seed brown. Type 20.  
 Branches erect . . . . . Late in flowering.

II. Late ripening. (*Arhar*).

## 1. Flowers yellow, back of standard with self coloured veins.

## A. Pods green.

## i. Seed distinctly white. Type 21.

(a) Branches erect.

(b) Branches spreading.

## ii. Seed large white. Type 22.

Branches erect, sparse.

## iii. Seed white. Type 23.

(a) Branches erect.

(b) Branches spreading.

## iv. Seed brown. Type 24.

(a) Branches erect.

(b) Branches spreading.

## B. Pods green blotched with maroon.

## i. Seed white. Type 25.

(a) Branches erect.

(b) Branches spreading.

## ii. Seed brown. Type 26.

Branches erect.

## iii. Seed dark mottled brown. Type 27.

Branches spreading.

## C. Pods dark.

## i. Seed white. Type 28.

(a) Branches erect.

(b) Branches spreading.

## ii. Seed brown. Type 29.

Branches erect.

## 2. Flowers yellow, back of standard veined with red.

## A. Pods large green.

## i. Seed large white. Type 30.

Branches erect.

## ii. Seed large brown. Type 31.

Branches erect.

## B. Pods green blotched with maroon.

## i. Seed white. Type 32.

Branches spreading.

## ii. Seed brown. Type 33.

Branches erect.

## C. Pods dark.

## i. Seed white. Type 34.

Branches erect.

## ii. Seed brown. Type 35.

(a) Branches erect.

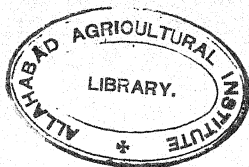
(b) Branches spreading.

## 3. Flowers yellow, back of standard light purple.

Pods green blotched with maroon.

Seed brown. Type 36.

Branches erect.



*Description of the types.*(i) *Turs.*

*Type 1. c.* Plants short (120 cm.); medium in flowering. Branches spreading at an angle of 60°. Flowers pale yellow; back of standard with self coloured veins; pods green; seed white, small, round.

*Type 2. b.* Plants very early in flowering and ripening. Branches semi-erect, at an angle of 50°. Leaves deep green. Peduncle short (5 cm.). Flowers pale yellow; back of standard with self coloured veins; pods green; seed light brown, medium, round.

*Type 3. d.* Plants short, early in flowering. Branches arising at an angle of 40°, but bending downwards. Leaves small (10.4 cm.). Peduncle short (4 cm.). Flowers pale yellow; back of standard with self coloured veins. Pedicle and calyx green. Pods blotched with maroon. Seed white.

*Type 4. a.* Plants late in flowering. Branches very erect, at an angle of 30°. Leaves small (11 cm.). Peduncle short (4 cm.). Flowers pale yellow; back of standard with self coloured veins. Pedicle and calyx green. Pods blotched with maroon. Seed brown, small.

*Type 5. a.* Plants medium in flowering. Branches erect, at an angle of 45°. Flowers pale yellow; back of standard with self coloured veins. Pods dark. Seed white, medium.

*Type 6. c.* Plants dwarf (120 cm.) early in flowering, with characteristic type of spreading branches which arise almost at right angles high up on the main stem. Leaves small (10.5 cm.). Peduncle short (4 cm.). Flowers pale yellow; back of standard with self coloured veins. Pedicle and calyx green. Pods dark; seed light brown, small.

*Type 7.* Plants early in flowering. Branches spreading at an angle of 60°. Peduncle short (5 cm.). Flowers pale yellow; back of standard veined with red. Pods green; seed brown medium with two prominent ridges on the hilum.

*Type 8. b.* Plants medium in flowering. Branches spreading at an angle of 55°. Flowers pale yellow; back of standard veined with red. Pods blotched with maroon; seed white, medium.

*Type 9. b.* Plants tall (175 cm.), robust, medium in flowering. Stem red. Branching very characteristic and sparse; branches arising very high up on the main stem, from 17th node, 50 cm. above ground at an angle of 55°. Leaves deep green; pedicle and calyx green, faintly streaked. Flowers pale yellow; back of standard veined with red. Pods blotched with maroon; seed an attractive brown colour, large.

*Type 10.* Plants medium in flowering. Branches very spreading. Peduncle long (9 cm.). Flowers pale yellow; back of standard veined with red. Pods dark; seed light brown.

*Type 11. a.* Plants tall, medium in flowering. Stem and branches red. Branching erect, at an angle of  $45^{\circ}$ . Leaves dark green. Flowers deep yellow; back of standard with self coloured veins. Pedicle and calyx green; streaked on the upper side. Pods blotched with maroon; seed white, medium.

*Type 12. a.* Plants tall (170 cm.) medium in flowering. Branches erect at an angle of  $40^{\circ}$ . Flowers deep yellow; back of standard with self coloured veins. Pods blotched with maroon; seed brown, large.

*Type 13. c.* Plants very tall (192 cm.). Branches erect at an angle of  $45^{\circ}$ . Leaves small (11.9 cm.). Pedicle and calyx green with few streaks on the upper side. Flowers yellow; back of standard veined with red. Pods small (5.5 cm./0.6 cm.) blotched with maroon; seed small, brown.

*Type 14. a.* Plants medium in flowering. Branches erect, at an angle of  $40^{\circ}$ . Leaves coarse with broad terminal leaflet. Flowers deep yellow; back of standard veined with red. Pedicle and calyx green, with few streaks on the upper side. Pods dark; seed light brown, large, round.

*Type 15.* Plants very early in flowering. Branching sparse. Flowers deep yellow; back of standard with deep purple veins, purple spreading between veins in lower half of standard. Pods green; seed white, medium. (A fixed type from a cross between T. 16. b.  $\times$  T. 19.)

*Type 16. b.* Plants medium in flowering. Branches spreading at an angle of  $50^{\circ}$ , drooping. Pedicle green, faintly streaked at the base. Calyx green; teeth red. Flowers deep yellow; back of standard with deep purple veins, purple spreading between the veins in lower half of standard. Pods green; seed brown.

*Type 17. b.* Plants medium in flowering. Stem and branches reddish purple. Branches spreading at an angle of  $50^{\circ}$ , drooping. Leaves dark green. Flowers deep orange yellow. Pedicle and calyx green, streaked on the upper side. Pods blotched with maroon; seed purplish black, medium.

*Type 18. a.* Plants early in flowering. Colour of the stem, leaves and flowers lighter than in Type 17. Branches erect, at an angle of  $40^{\circ}$ . Leaves dark green, terminal leaflet broad (6.6 cm./3.0 cm.). Peduncle short (5.5 cm.). Flowers orange yellow; pods dark; seed purplish black.

*Type 19.* Plant very early in flowering and ripening. Stem slender, very sparsely branched. Branches on an average 3, erect, at an angle of  $40^{\circ}$ , arising very high on the main stem from 17th node which is about 42 cm. above ground. Leaves large (17.3 cm.); petiole 4.6 cm. Ratio of the terminal leaflet—length / width—10.3 cm./3.3 cm. Colour dark green. Flowers deep yellow, large, 3 cm. Pedicle 1 cm. with dark purple streaks. Calyx 1.1 cm. covered with many dark purple streaks. Standard 2 cm./1.8 cm., its back purple. Pods wider than in other types (7 cm./1.3 cm.), blotched with maroon. Seed white, broadest across the hilum with two prominent ridges on the latter.

This type stands out quite clearly from the others on account of its sparsely branched habit, large leaves, purple flowers and wide pods.

*Type 20.* Plants late in flowering. Branches erect, at an angle of  $45^{\circ}$ . Leaves dark green. Pedicle covered with dark purple streaks. Calyx with many dark purple streaks. Flowers deep yellow; back of standard purple. Pods blotched with maroon; seed light brown, round.

(ii) *Arhars.*

*Type 21.* Plants with erect branches, arising at an angle of  $45^{\circ}$ , and curving inwards. Flowers yellow; back of standard with self coloured veins; pedicle and calyx green; teeth red; pods green; seed distinctly white.

*Type 22.* Plants with leaves, flowers, pods and seeds very large. Branching very sparse, high up on the main stem. Flowers yellow on short peduncles; back of standard with self coloured veins. Pods green; seed white, with two prominent ridges on the hilum.

(Essentially a garden variety grown for its large pods which are used as vegetable.)

*Type 23.* Plants with erect branches, arising at an angle of  $45^{\circ}$ , and curving inwards. Leaves quite distinct from those of other types. Terminal lobe broadest below the middle and tapering sharply towards the apex; its joint deflexed and the midrib much curved, raising the terminal leaflet above the level of the other two. Flowers yellow; back of standard with self coloured veins. Pods green; seed white, small.

*Type 24.* Plants much branched. Branches profusely spreading, at an angle of  $70^{\circ}$ . Flowers yellow; back of standard with self coloured veins; pedicle and calyx green. Pods green; seed brown, small.

*Type 25.* Plants with erect branches arising at an angle of  $50^{\circ}$ , and curving inwards. Flowers yellow; back of standard with self coloured veins. Pedicle and calyx green. Pods blotched with maroon; seed white, small, with two ridges on the hilum.

*Type 26.* Plants tall (240 cm.). Branches very erect, at an angle of  $30^{\circ}$ , arising high up on the main stem from 10th node, 26 cm. above ground. Terminal leaflet broad, ratio 8.2/3.2 cm. Flowers yellow; back of standard with self coloured veins. Pedicle and calyx green. Pods blotched with maroon; seed brown.

*Type 27.* Plants short, much branched. Branches erect, at an angle of  $50^{\circ}$ , curving inwards. Flowers yellow; back of standard with self coloured veins. Pedicle and calyx green. Pods blotched with maroon; seed dark mottled-brown, flattened, rectangular or square.

*Type 28.* Plants tall with very erect branches, arising at an angle of  $30^{\circ}$ . Flowers yellow; back of standard with self coloured veins. Pedicle and calyx green. Pods dark. Seed white, medium.

*Type 29.* Plants with erect branches, at an angle of  $35^{\circ}$ . Flowers yellow; back of standard with self-coloured veins. Pods dark. Seed brown, large.

*Type 30.* Flowers yellow; back of standard veined with red. Pods large green; seed large white.

*Type 31.* Plants with erect branches at an angle of 40°. Flowers yellow; back of standard veined with red. Pods large, green. Seed large; an attractive brown colour.

*Type 32.* Plants with branches at an angle of 55°. Flowers yellow; back of standard veined with red. Pods blotched with maroon. Seed white.

*Type 33.* Plants short, with erect branches, arising at an angle of 50°, curving inwards. Flowers yellow; back of standard veined with red. Pods blotched with maroon. Seed brown.

*Type 34.* Plants tall, branches very erect, at an angle of 30°. Flowers yellow; back of standard veined with red. Pods dark. Seed white.

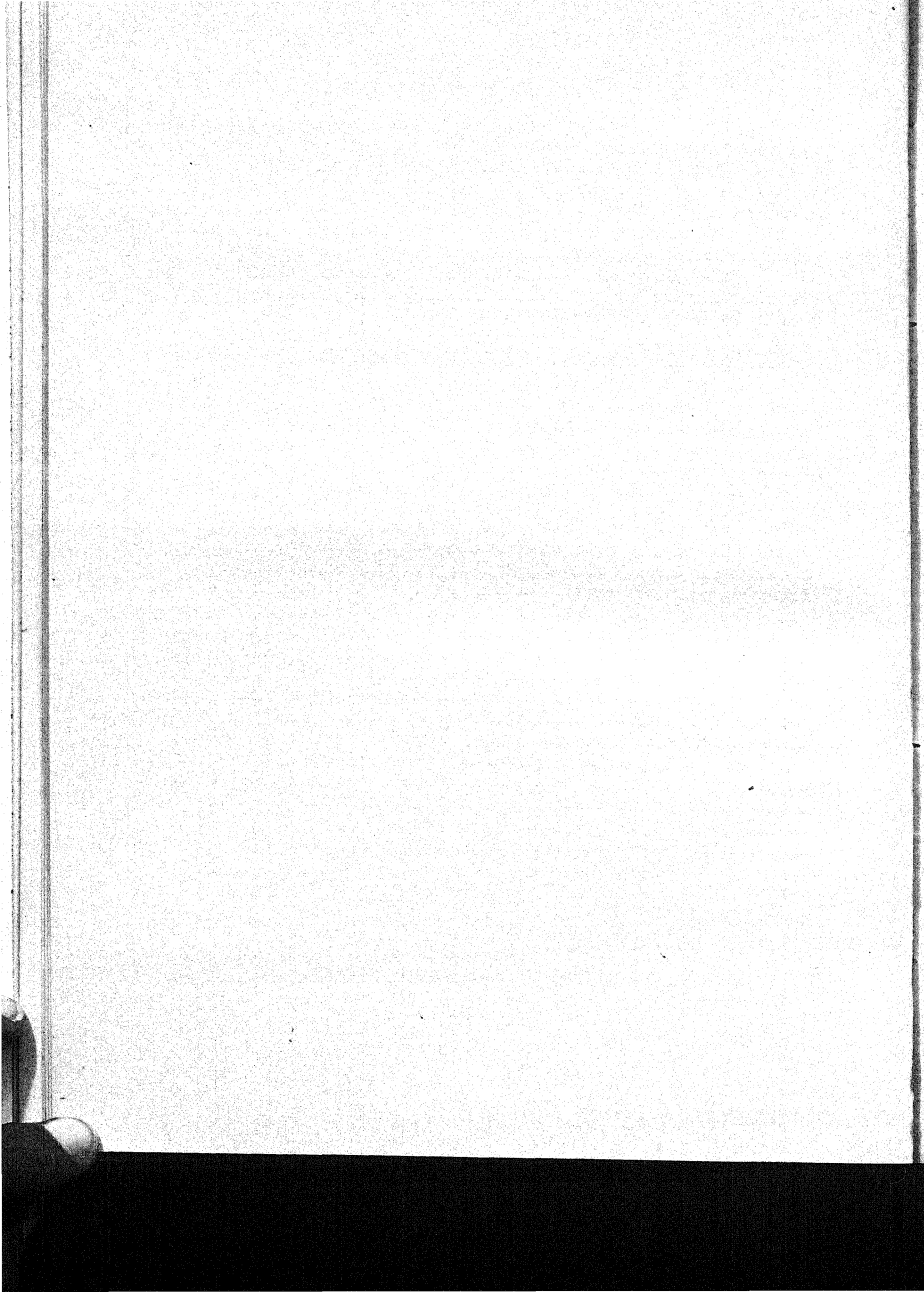
*Type 35.* Plants short, much branched. Branches spreading. Flowers yellow; back of standard veined with red. Pods dark. Seed light brown.

*Type 36.* Plants with branches erect, at an angle of 50°. Pedicle and calyx green. Flowers yellow; back of standard light purple. Pods blotched with maroon. Seed light brown.

### III. IMPROVEMENT.

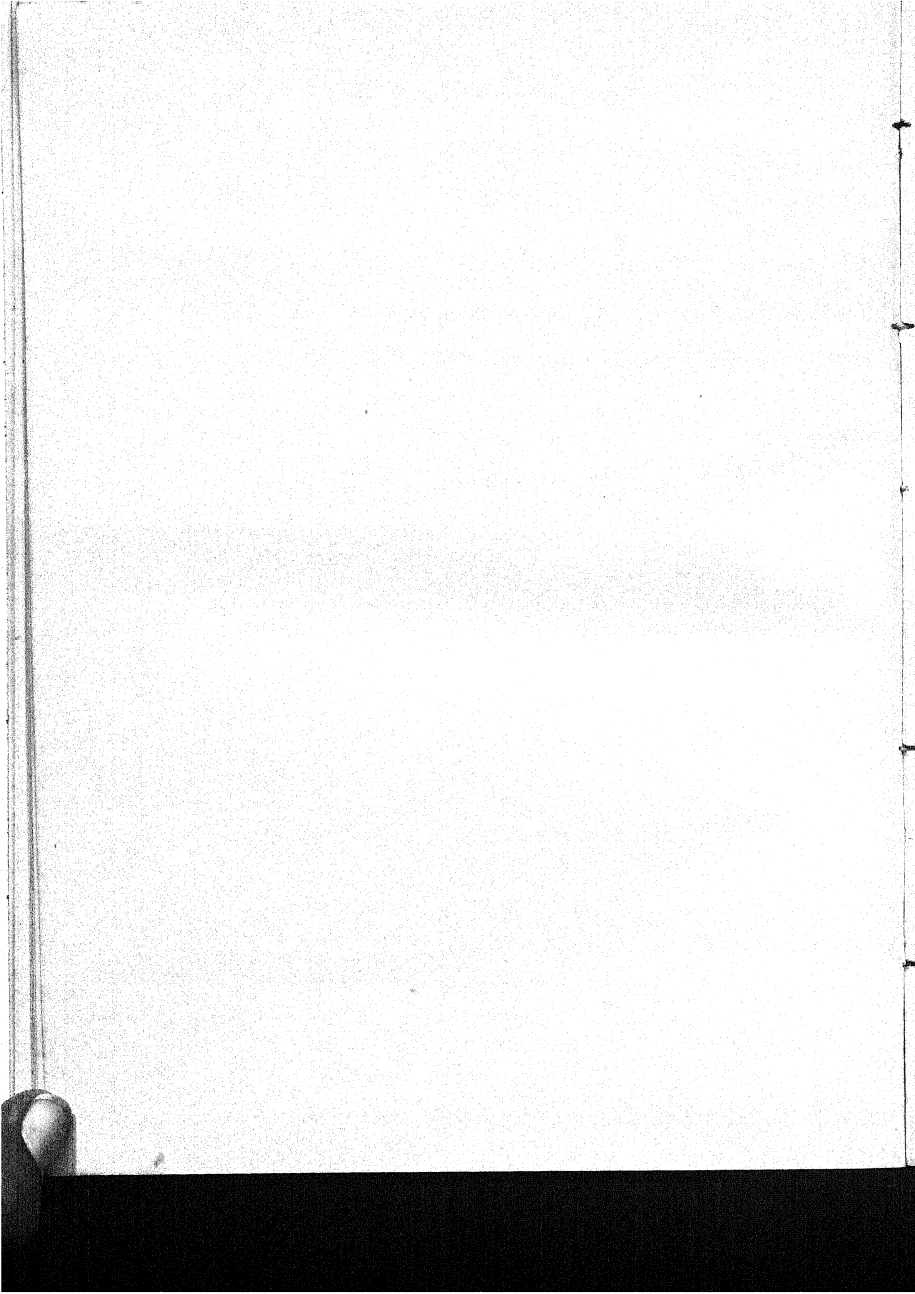
The chief problems associated with the improvement of *Cajanus indicus* are concerned with the production of high yielding and wilt-resistant forms. As has been pointed out elsewhere, this crop is subject to a great deal of natural cross-fertilization and, therefore, is not an easy one to work on. However, after completion of the work of systematic examination of the forms met with in the various tracts and their classification into types, attention was diverted to raising pure lines and making a comparative study of the selected types. The inferior types were successively eliminated until there were but a few promising strains left, which were placed on trial in the conditions under which the crop is ordinarily grown by the cultivator. These experiments have now reached a stage when one can speak more freely. E. B. 3—a selection from Type 8—has so consistently done well on the various farms where the trials were conducted, that it can safely be given out to the cultivator in the Nagpur Wardha plain and Berar. A considerable demand for this strain has already sprung up and on the Experimental Farm, Nagpur, it has completely replaced all other varieties. Besides being early and high yielding, it is reputed to possess flavour and quality of pulse much liked by the public.

D



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# STUDIES IN INDIAN PULSES.

## (2) SOME VARIETIES OF INDIAN GRAM (*Cicer arietinum* L.)

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### I. INTRODUCTION.

Gram (*Cicer arietinum* Linn.) has been the subject of a previous publication in these Memoirs<sup>1</sup>. The earlier work deals with the biology of the plant and describes 25 different types which were isolated from seed samples collected from the Districts of Aligarh, Muzaffarnagar and Saharanpur in the United Provinces and a small part of Bihar and Orissa round Pusa. The present paper describes another 59 types which were collected from all over India in 1924.

The total area in British India under gram in 1926-27 amounted to 14,582,000 acres and the total yield was 3,979,000 tons; an average of about 620 lb. per acre. These figures do not show any material difference from those quoted by the Howards and Abdur Rahman Khan for the year 1911-12. The export trade is very fluctuating ranging from about 327,000 tons (1917-18) to 4,900 tons (1921-22).

TABLE I.  
*Exports of gram.*<sup>2</sup>

Year	Total Export	To British Empire
	Tons	Tons
1928-29 . . . . .	13,969	7,208
1927-28 . . . . .	17,567	8,272
1926-27 . . . . .	13,992	6,476

<sup>1</sup> Howard, A., Howard, G. L. C., and Abdur Rahman Khan.—Some Varieties of Indian Gram (*Cicer arietinum*, L.). *Mem. Dept. Agri. India, Bot. Ser.*, Vol. VII, No. 6, 1915.

<sup>2</sup> Annual Statement of the Sea-borne trade of British India with the British Empire and Foreign countries, Vol. I.

TABLE I—*contd.*  
*Exports of gram—contd.*

Year	Total Export		To British Empire	
	Tons		Tons	
1925-26 . . . . .	30,615		7,832	
1924-25 . . . . .	142,495		64,535	
1923-24 . . . . .	71,308		34,634	
1922-23 . . . . .	21,957		16,832	
1921-22 . . . . .	4,038		4,675	
1920-21 . . . . .	5,733		5,103	
1919-20 . . . . .	5,190		4,759	
1918-19 . . . . .	232,193		262,187	
1917-18 . . . . .	327,062		320,994	
1916-17 . . . . .	38,222		33,157	
1915-16 . . . . .	32,404		18,705	
1914-15 . . . . .	23,298		5,528	
1913-14 . . . . .	69,596		20,106	
1912-13 . . . . .	144,919		43,974	
1911-12 . . . . .	346,742		134,822	
1910-11 . . . . .	45,450		22,403	
1909-10 . . . . .	53,496		41,664	
1908-09 . . . . .	7,578		6,443	
1907-08 . . . . .	42,693		34,597	
1906-07 . . . . .	42,329		26,038	
1905-06 . . . . .	20,883		17,846	
1904-05 . . . . .	38,864		14,154	
1903-04 . . . . .	18,251		12,307	
1902-03 . . . . .	20,818		16,442	
1901-02 . . . . .	15,998		14,593	
1900-01 . . . . .	11,675		10,674	
1899-1900 . . . . .	13,921		11,144	

## YIELD AND STERILITY.

The normal yield of the Pusa Types 17 and 25 in Bihar is about 1,200 lb. per acre, the highest recorded at Pusa being 2,843 lb. per acre. Among the factors which affect the yield of gram, the amount of sterility, *i.e.*, of pods which do not contain any seeds, and the proportion of pods which contain more than one seed have to be reckoned. These factors vary in different types and are probably inherent in the types; they are distinct from that form of sterility which depends upon the failure of pollination owing to unfavourable climatic conditions. In this latter case, the flowers fall off and no pod is formed.

Observations on the original 25 types of Pusa grams have given the following percentages of sterile, one-seeded, and two or more seeded pods:—

TABLE II.  
*Sterility in gram.*

Type No.	Percentage of 1-seeded pod		Percentage of 2 or > 2-seeded pods		Percentage of sterile pods	
	1926-27	1928-29	1926-27	1928-29	1926-27	1928-29
1 . . . . .	70	76	9	2	21	22
2 . . . . .	57	75	13	4	30	21
3 . . . . .	57	65	16	3	27	32
4 . . . . .	61	74	13	0	26	17
5 . . . . .	68	78	9	3	24	19
6 . . . . .	70	50	14	26	16	24
7 . . . . .	56	37	22	20	22	34
8 . . . . .	48	52	37	30	15	18
9 . . . . .	30	36	40	32	21	32
10 . . . . .	35	40	55	38	10	22
11 . . . . .	47	30	45	13	8	57
12 . . . . .	57	61	37	10	6	20
13 . . . . .	26	19	31	8	43	73
14 . . . . .	16	33	72	53	12	14
15 . . . . .	37	54	48	35	15	11
16 . . . . .	43	57	31	39	26	4
17 . . . . .	43	36	32	58	25	6
18 . . . . .	38	49	45	43	17	8

TABLE II—*contd.*  
*Sterility in gram—contd.*

Type No.	Percentage of 1-seeded pod		Percentage of 2 or > 2-seeded pods		Percentage of sterile pods	
	1926-27	1928-29	1926-27	1928-29	1926-27	1928-29
10 . . . . .	46	47	40	45	14	8
20 . . . . .	38	46	48	33	14	21
21 . . . . .	24	47	66	45	10	8
22 . . . . .	30	41	42	41	19	18
23 . . . . .	25	39	60	48	15	13
24 . . . . .	33	41	46	53	21	6
25 . . . . .	24	49	51	38	25	13

On the average the three best yielding Pusa types (17, 18, 25) all show a relatively high proportion of pods containing 2 or more seeds, while the low yielding types (11 and 13) have a high percentage of sterile pods. Pods containing 2 or more seeds appear to be more frequent in the pink flowered types (14-25), while sterility is generally lower in these types than in the white flowered types (1-12). The co-efficient of correlation between yield and percentage of more than 1-seeded pods for the year 1926-27 for all the types is  $+0.57 \pm .0907$  and between yield and sterility  $-0.616 \pm .0835$ . There is obviously a seasonal variation in the amount of sterility which requires investigation.

#### MORPHOLOGICAL CHARACTERS.

*Habit.* The range in general habit in gram is well illustrated in the previous memoir. Plants are either erect or spreading. This distinction is only apparent when the plants are young, at the time of flowering all types appear more or less erect. The habit is generally correlated with the time of maturity; late varieties are generally spreading with numerous lateral branches and early varieties are erect with fewer lateral branches. The habit does not constitute a very definite character in classifying the types.

*Leaves.* The types 1 to 5 of the original Pusa grams have large leaflets. In the present paper the leaflets of all types have been measured and leaflets having a length of more than 15 mm. are called large; leaflets between 11 and 15 mm. in length are classed as medium and below 11 mm. as small.

The colour of the foliage varies considerably in the different types. This character is best observed in the mass and should be seen in the early morning with the sun behind the observer. The colour varies with the age of the plants. When the foliage growth is quick it is lighter and when slow it is darker. The

best time for observing the colour is when the plants are in full flower. The colour ranges from light yellowish green to dark bluish green and in many types a distinct reddish tinge can be seen. Red colour when present generally exists on the margin of the leaf, on the mid rib, in the axil of the leaf, on the petiole and more rarely on the stem. The degree of development of red colour is, to a considerable extent, dependent on the amount of sun light falling on the plant—this character therefore varies with the environment and is not a reliable taxonomic criterion.

*Number of flowers.* The original 25 types all possess flowers which are solitary on the pedicels; among the new types we have found certain varieties, collected at Partabgarh, which have 2 flowers on each pedicel (Text-fig. 1, Type 83).

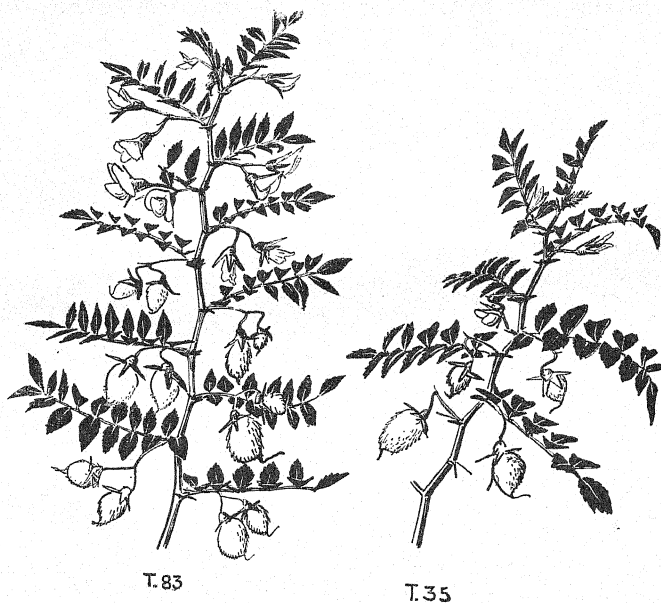


Fig. 1.

*Size of flowers.* The size of the flower is generally correlated with the size of the seed.

*Colour of the flowers.* The colour of the flower (Plate I) may be white, greenish white, some shade of pink, lilac or blue. The colour changes with the age of the flowers and care should be taken to observe colour of fresh flowers only in the early part of the day. In the previous memoir the following shades of pink colour were recognised :—

- (a) Standard light pink, wings violet above, pink below, with a slight bluish tinge (Types 14 and 19).
- (b) Standard and wings pale pink with a general bluish tinge (Type 20).
- (c) Standard light pink, wings with a bluish tinge.
- (d) Standard very light pink, wings pink with a general bluish tinge.
- (e) Standard and wings pink with a deep bluish tinge (Type 24).
- (f) Standard and wings reddish (Type 25).

The differences between classes (b), (c), and (d) are so slight that we consider that the separation of these classes cannot be reliable; we therefore include all these classes as one class under (b). In addition to the above types of flower two new types were found in the new varieties. These were :—

- (g) Standard and wings reddish with a general bluish tinge (Type 42).
- (h) Standard pale lilac, wings pale pink with a pronounced bluish tinge (Type 81).

In all the types, except Type 1, the corolla is glabrous and caducous but in Type 1 the standard is pubescent and persistent.

*Pods.* The average length and breadth of pods are given in the description of types. Pods measuring 25 mm. or more in length are classed as large (Text-fig. 2, Type 2), between 20 and 25 mm. as medium (Text-fig. 2, Type 28), and below 20 mm. as small (Text-fig. 2, Type 35).

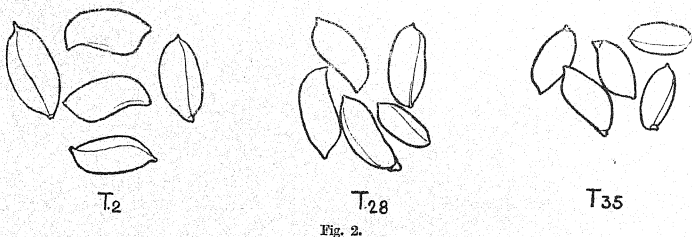
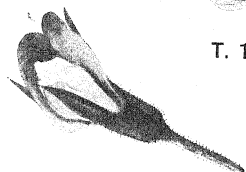


Fig. 2.

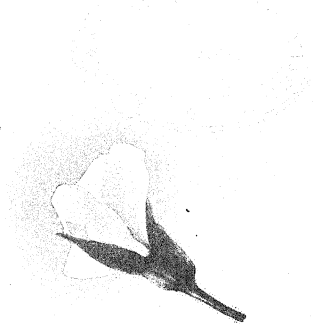
*Seed.* Seeds are classed according to their shape as irregular or round (Plate II). The surface may be smooth, puckered, granulated or rough. A rough seed has a surface which to the touch feels like sand paper. The seeds vary considerably in



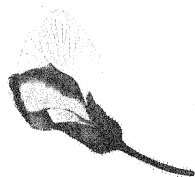
T. 18.



T. 1.



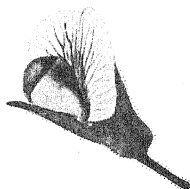
T. 2.



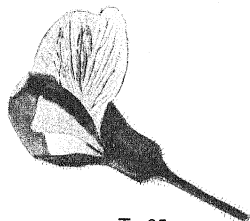
T. 14.



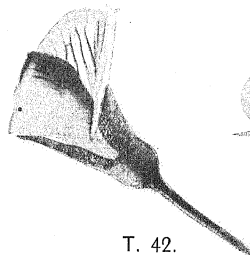
T. 20.



T. 24.



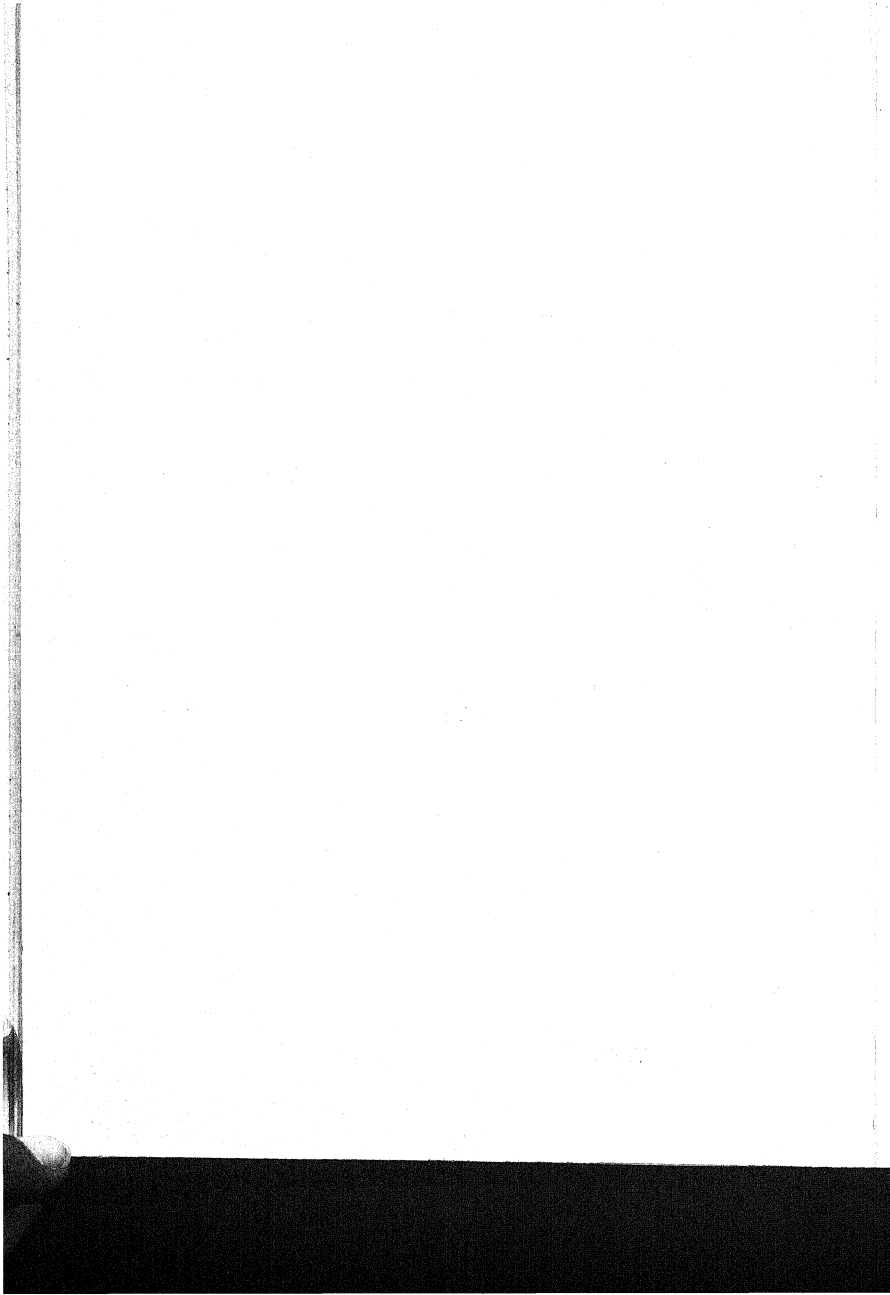
T. 25.



T. 42.



T. 81.



T.2.



T.40.



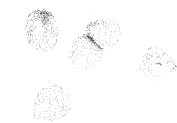
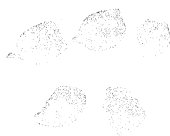
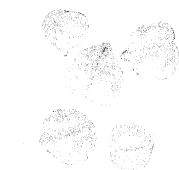
T.43.



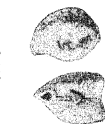
T.28.



T.29.



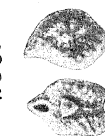
T.10.



T.72.



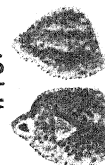
T.66.



T.12.



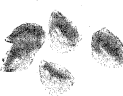
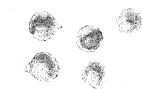
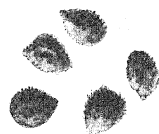
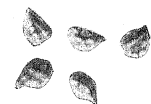
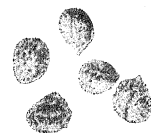
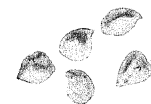
T.45.

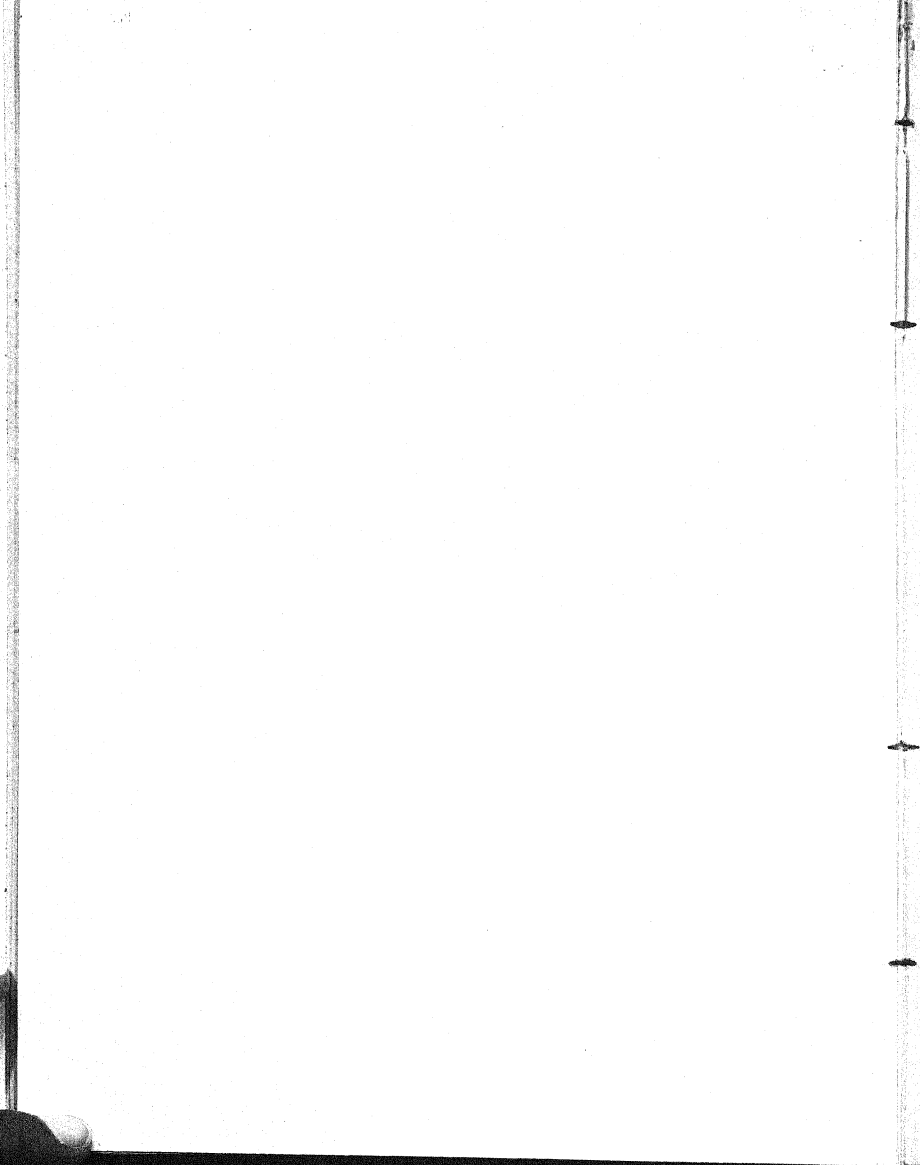


T.11.



T.24.





size and as a measure of size the weight of 1,000 seeds has been taken. When 1,000 seeds weigh 275 gm. or more they are classed as large, when the weight is between 175 and 275 gm. they are classed as medium and when below 175 gm. as small.

The colour of seed in gram varies to a certain extent in the same plant and even in the same pod according to maturity, but the colour of mature grains is a very good constant character. The following colours have been distinguished :—

- (1) White, (2) Light fawn, (3) Orange, (4) Reddish fawn, (5) Yellowish brown, (6) Reddish brown, (7) Dark reddish brown, (8) Plain brown, (9) Brown with dark bluish tinge.

According to the seed character, types may be classified as follows:

Seed colour white—

Shape round—

Surface slightly puckered, small . . . . . 8.

Surface puckered—

Size small . . . . . 7, 9, 30, 31, 32.

„ medium . . . . . 27, 28.

„ large . . . . . 1, 2, 3, 4, 5, 26.

Shape irregular—

Surface smooth, small . . . . . 6.

„ slightly granulated, small . . . . . 33.

Seed colour light fawn, irregular, slightly granulated, small . . . . 34.

„ „ orange, smooth, small	.	.	.	.	.	.	.	35.
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22	22	22	22	medium	.	.	.	.	.	.	.	29.
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„ „ reddish fawn, slightly irregular, slightly granulated, small . . 10.

Seeds yellow pink, irregular, smooth, medium . . . . . 36—42.

..	..	..	..	distinctly granulated, medium	43.
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„ brown, yellowish, ir regular, smooth, small . . . . . 15, 17, 19, 20, 25,  
46 to 63 and 65.

22	22	22	22	slightly granulated, small	.	.	.	.	66, 67, 82, 83, 84.
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39	39	39	39	rough, small.	.	.	.	.	.	68 to 72.
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“ reddish “ smooth, small . . . . . 12, 64.

„ „ dark reddish, irregular, smooth, small . . . . . 14, 16, 18, 21, 22,  
23, 73 to 78.

"	"	"	"	"	granulated, large, mutation	.	.	.	79.
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" " " " " rough, medium . . . . . 44, 45.

.. plain brown, round, smooth, small . . . . . 11, 13.

„ brown with dark bluish tinge, irregular, smooth, small . . . . 24, 80, 81.

## KEY TO THE CLASSIFICATION OF TYPES.

I. Standard persistent . . . . .	1
II. Standard caducous—	
(A) Flowers white—	
a. Seed large—	
1. Grain white—	
(a) Shape round—	
(1) Surface puckered—	
i. Pods large—	
(i) Plants early—	
Type 2 earlier than Type 3 . . . . .	2
Type 3 early but later than Type 2 . . . . .	3
(ii) Plants intermediate in maturity . . . . .	26
(iii) Plants late . . . . .	4
(iv) Plants very late . . . . .	5
b. Seed medium in size—	
1. Grain white—	
(a) Shape round—	
(1) Surface puckered—	
i. Pods large—	
Leaves very dark green . . . . .	27
ii. Pods medium in size—	
Leaves dark green . . . . .	28
2. Grain orange—	
(a) Shape round—	
(1) Surface smooth—	
i. Pods medium in size—	
Leaves light green . . . . .	29
Seed small—	
1. Grain white—	
(a) Shape round—	
(1) Surface puckered—	
i. Pods medium in size—	
(i) Plants early—	
Leaves dark green . . . . .	7
(ii) Plants medium in ripening—	
(i) Leaves light green—	
habit spreading . . . . .	8
(ii) Leaves dark green—	
habit of plants erect . . . . .	30
(iii) Plants very late . . . . .	9
ii. Pods small—	
(i) Plants early—	
(i) Leaves green—	
habit of plants erect . . . . .	31
(ii) Plants medium in maturity—	
(i) Leaves dark green—	
habit spreading . . . . .	32

(b) Shape of seeds irregular—	
(1) Surface smooth . . . . .	6
(2) „ slightly granulated . . . . .	33
3. Grain light fawn—	
(a) Shape irregular—	
(1) Surface slightly granulated . . . . .	34
4. Grain orange—	
(a) Shape round—	
(1) Surface smooth . . . . .	35
5. Grain reddish fawn—	
(a) Slightly irregular—	
(1) Slightly granulated . . . . .	10
6. Grain reddish brown—	
(a) Irregular—	
(1) Smooth . . . . .	12
7. Grain brown—	
(a) Round—	
(1) Smooth . . . . .	11
(B) Flowers blue . . . . .	13
(C) Flowers pink—	
Flowers solitary—	
a. Seeds large—Mutation . . . . .	79
b. Seeds medium—	
1. Grain yellow pink—	
(a) Irregular—	
(1) Smooth—	
i. Pods medium in size—	
i. Flower sub-class B—	
(ii) Plants early—	
(i) Leaves light green . . . . .	36
(ii) Leaves green . . . . .	37
(iii) Leaves dark reddish green . . . . .	38
(ii) Plants medium in ripening—	
(i) Leaves light green . . . . .	39
(ii) Leaves dark green . . . . .	40
ii. Pods small in size—	
i. Flower sub-class B—	
(i) Leaves dark green . . . . .	41
ii. Flower sub-class G . . . . .	42
(2) Seeds distinctly granulated . . . . .	43
2. Seeds dark reddish brown—	
(a) Irregular—	
(1) Rough—	
i. Flower sub-class A . . . . .	44
ii. Flower sub-class B—	
(i) Plants early—	
Leaves dark green—	
Axil red . . . . .	45

## c. Seeds small—

## 1. Grain yellowish brown turning to red brown—

## (a) Shape irregular—

## (1) Surface smooth—

i. Pods medium. . . . . 46

## ii. Pods small—

## i. Flower class A—

## (i) Plants early—

## (i) Leaves dark green—

No red colour in the axil . . . 47

Occasional red in the axil . . . 48

Distinct red colour in axil . . . 49

## (ii) Plants medium in maturity—

(i) Leaves light green . . . 50

(ii) Leaves green . . . 51

(iii) Leaves dark green . . . 15

(iv) Leaves reddish dark green . . . 52

## (iii) Plants late—

## (i) Leaves light green—

Slight red colour in the axil . . . 19

## (ii) Leaves yellowish green—

No red colour in the axil . . . 17

## ii. Flower class B—

## (i) Plants early—

(i) Leaves green . . . 53

## (ii) Leaves dark green—

No colour in the axil . . . 54

Slight colour in the axil . . . 55

Distinct colour in the axil . . . 56

(iii) Leaves very dark green . . . 20

## (ii) Plants medium in maturity—

(i) Leaves light green . . . 57

(ii) Leaves green . . . 58

(iii) Leaves dark green . . . 59

## (iii) Plants late—

(i) Leaves light green . . . 60

(ii) Leaves green . . . 61

## iii. Flower class F—

## (i) Plants early—

(i) Leaves light green . . . 62

## (ii) Plants medium in maturity—

(i) Leaves green . . . 63

(ii) Leaves dark green . . . 25

## iv. Flower class G—

## (i) Plants early—

## (i) Leaves dark green—

Slight colour in the axil . . . 64

Considerable colour in the axil . . . 65

## (2) Seeds slightly granulated—

## i. Pods small—

## i. Flower class A—

## (i) Plants early—

(i) Leaves dark green . . . 66

ii. Flower class B— . . . 67

(3) Seed surface rough—	
i. Flower class B . . . . .	68
ii. " " E—	
(i) Plants early—	
Leaves dark green—	
Slight colour in the axil . . .	69
moderate colour in the axil . . .	70
(ii) Leaves very dark green . . .	71
iii. Flower class G . . . . .	72
2. Seeds dark reddish brown—	
(a) Shape irregular—	
Surface smooth—	
i. Pods small—	
ii. Flower class A—	
(i) Plants medium in maturity—	
(i) Leaves light green—	
Plants erect . . . . .	18
Plants spreading . . . . .	16
(ii) Leaves green—	
No colour in the axil . . . . .	73
Red colour in the axil . . . . .	74
(iii) Leaves reddish dark green . . . . .	75
(ii) Plants late—	
(i) Leaves light bluish green . . . . .	23
(ii) Leaves dark green . . . . .	14
ii. Flower class B—	
(i) Plants early—	
(i) Leaves light bluish green . . . . .	22
(ii) Leaves dark green . . . . .	76
(ii) Plants late—	
(i) Leaves dark green . . . . .	21
iii. Flower class G—	
(i) Leaves green, early in maturity . . . . .	77
(ii) Leaves dark green medium in maturity . . . . .	78
3. Seeds dark bluish brown—	
(a) Shape irregular—	
(1) Surface smooth—	
i. Pods small—	
i. Flower class E . . . . .	24
ii. Flower class G . . . . .	80
iii. Flower class H . . . . .	81
Flowers two on a peduncle—	
a. Seeds small—	
1. Seeds yellowish brown turning to reddish brown when mature—	
(a) Shape irregular—	
(1) Surface slightly granulated—	
i. Pods medium in size . . . . .	82
ii. Pods small—	
i. Flower class A . . . . .	83
ii. Flower class F . . . . .	84

DESCRIPTION OF THE TYPES.<sup>1</sup>

Type 1. Very late ; habit erect ; leaves dark green, leaflets large ( $15.2 \times 10.3$  mm.) ; flowers large, solitary, greenish white ; standard persistent, pubescent, green with a greenish white eye ; wings slightly pubescent, white with a greenish tinge at the edges ; keel glabrous, white ; pods large ( $26.9 \times 17.9$  mm.) ; seeds large, white with a reddish yellow tinge, round, puckered, weight of 1,000 seeds 410.5 gm. (Plate I).

Type 2. Early ; habit erect ; leaves dark green, leaflets large ( $17.6 \times 13.2$  mm.) ; flowers large, solitary, white ; standard caducous, glabrous ; wings glabrous ; pods large ( $26.8 \times 18.9$  mm.) ; seeds large, white with a reddish yellow tinge, round, puckered, weight of 1,000 seeds 408.5 gm. (Plates I and II).

Type 3. This type differs from Type 2 only in the time of maturity which is a little later.

Type 4. Late ; habit erect ; leaves dark green, leaflets large ( $17.6 \times 12.6$  mm.) ; flowers large, solitary, white ; standard caducous, glabrous ; wings glabrous ; pods large ( $27.6 \times 19.3$  mm.) ; seeds large, white with a reddish yellow tinge, round, puckered, weight of 1,000 seeds 392.0 gm.

Type 5. Very late ; habit erect ; leaves very dark green, leaflets large ( $21.3 \times 15.4$  mm.) ; flowers large, solitary, white ; standard caducous, glabrous ; pods large ( $27.7 \times 18.6$  mm.) ; seeds large, white with a reddish yellow tinge, round, puckered, weight of 1,000 seeds 399.5 gm.

Type 6. Early ; habit somewhat spreading ; leaves very light yellowish green, leaflets small ( $9.7 \times 6.0$  mm.) ; flowers small, solitary, white ; standard caducous, glabrous ; pods medium in size ( $24.3 \times 16.4$  mm.) ; seeds small, white with a yellow tinge, irregular, smooth, weight of 1,000 seeds 125.0 gm.

Type 7. Early ; habit spreading ; leaves dark green, leaflets small ( $8.4 \times 5.0$  mm.) ; flowers small, solitary, white ; standard caducous, glabrous ; pods medium in size ( $20.3 \times 12.9$  mm.) ; seeds small, white, with a yellowish tinge, round, puckered, weight of 1,000 seeds 120.0 gm.

Type 8. Intermediate in time of maturity ; habit spreading ; leaves light green, leaflets medium in size ( $13.2 \times 7.7$  mm.) ; flowers small, solitary, white ; standard caducous, glabrous ; pods medium in size ( $22.3 \times 13.7$  mm.) ; seeds small, white with a yellowish tinge, round, slightly puckered, weight of 1,000 seeds 123.5 gm.

Type 9. Very late ; habit very spreading with numerous side branches ; leaves very dark green, leaflets small ( $8.9 \times 6.0$  mm.) ; flowers small, solitary, white ; standard caducous, glabrous ; pods medium in size ( $20.5 \times 13.0$  mm.) ; seeds small, white with a yellowish tinge, round, puckered, weight of 1,000 seeds 114.5 gm. This type is of interest in that, inspite of its deep root system, which is a disadvantage at Pusa, it has so far given the highest monetary return per acre. In this form yield and quality are united in the same type.

<sup>1</sup> The descriptions of Types 1 to 25 are based on those in the previous Memoir with the addition of some characters and slight modifications in flower colour.

Type 10. Early; habit erect; leaves dark green, leaflets medium in size ( $11.3 \times 6.6$  mm.); flowers small, solitary, white; standard caducous, glabrous; pods small ( $18.8 \times 11.8$  mm.); seeds small, reddish fawn, slightly irregular, slightly granulated, weight of 1,000 seeds 92.0 gm. (Plate II).

Type 11. Very early as regards flowering, but late in maturing; habit very erect; leaves very dark green, leaflets medium in size ( $12.6 \times 7.2$  mm.); flowers small, solitary, white; standard caducous, glabrous; pods small ( $17.4 \times 12.5$  mm.); seeds small, bluish, brown; round, smooth, weight of 1,000 seeds 107 gm. (Plate II).

Type 12. Very early as regards flowering but late in maturing; habit erect; leaves light green, leaflets medium in size ( $12.5 \times 7.2$  mm.); flowers small, solitary; white; standard caducous, glabrous; pods small ( $18.2 \times 12.0$  mm.); seeds small, reddish brown, irregular, smooth; weight of 1,000 seeds 126 gm. (Plate II).

Type 13. Very early; habit erect, leaves very dark green, leaflets medium in size ( $12.1 \times 7.2$  mm.); peduncles dark blue; flowers small, solitary, blue fading to dark blue; standard caducous, glabrous; light blue with a somewhat yellowish light blue eye and violet veins; wings deep blue; keel blue; pods small ( $18.2 \times 12.2$  mm.); seeds small, bluish brown, round, smooth; weight of 1,000 seeds 105.5 gm. (Plate I).

Type 14. Late; habit slightly spreading; leaves dark green with slight redness on the teeth of leaflets and on the midrib, leaflets medium in size ( $11.5 \times 7.0$  mm.); flowers small, solitary, pink; standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge; pods small ( $17.1 \times 12.2$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 118.5 gm. (Plate I).

Type 15. Intermediate in time of maturity; habit erect; leaves dark green, leaflets small ( $9.6 \times 5.8$  mm.); flowers small, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge; pods small ( $17.0 \times 11.7$  mm.); seeds small, yellowish brown turning to reddish brown on maturity, irregular, smooth, weight of 1,000 seeds 106.5 gm.

Type 16. Intermediate in time of maturity; habit slightly spreading; leaves light green with slight redness on the teeth of the leaflets and on the midrib, leaflets medium in size ( $11.2 \times 7.0$  mm.); flowers small, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge; pods small ( $17.9 \times 12.1$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 128.0 gm.

Type 17. Late; habit slightly spreading; leaves yellowish green with slight redness on the apices of the teeth of the leaflets, midrib reddish, leaflets medium in size ( $11.3 \times 6.1$  mm.); flowers small, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge; pods small ( $19.7 \times 13.0$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, smooth; weight of 1,000 seeds 125.5 gm.

Type 18. Intermediate in time of maturity; habit erect; leaves light green, slight reddening on the margins of the leaflets and deeper reddening on the midrib, leaflets medium in size ( $14.7 \times 7.2$  mm.); flowers small, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge; pods small ( $18.2 \times 12.7$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 122.0 gm.

Type 19. Late; habit erect; leaves light green, leaflets small ( $10.0 \times 5.7$  mm.); slight red colour in the axil of leaves; flowers small, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge; pods small ( $19.2 \times 12.4$  mm.); seeds small, yellowish brown, irregular, smooth, weight of 1,000 seeds 109.5 gm.

Type 20. Early; habit very erect; leaves very dark green with slight reddening of the margins of the teeth of the leaflets, leaflets small ( $10.1 \times 5.9$  mm.); flowers small, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods small ( $19.8 \times 12.5$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, smooth, weight of 1,000 seeds 124.6 gm. (Plate I).

Type 21. Late; habit somewhat erect; leaves dark green with some redness on the teeth of the leaflets which is strongly developed on the midrib and in the angle at the base of the side branches, leaflets medium in size ( $12.8 \times 6.6$  mm.); flowers small, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods small ( $18.2 \times 13.2$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 123.0 gm.

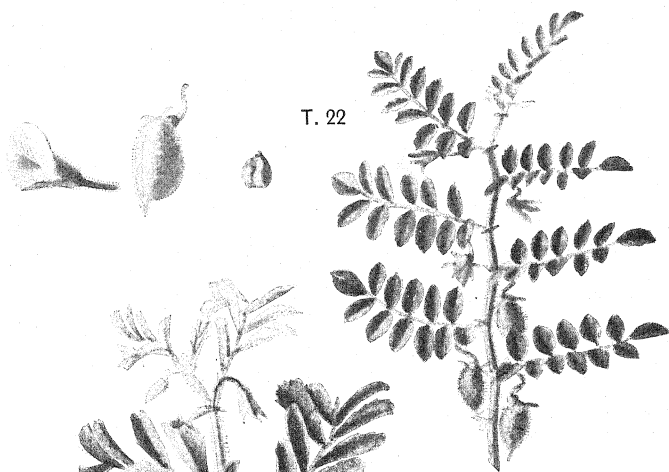
Type 22. Early; habit erect; leaves light bluish green, leaflets small ( $10.6 \times 5.6$  mm.); flowers small, solitary, pink, standard and wings pale pink with a general bluish tinge; standard caducous, glabrous; pods small ( $16.4 \times 12.1$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 120.0 gm. (Plate III).

Type 23. Late; habit erect; leaves light bluish green, leaflets medium in size ( $11.6 \times 6.8$  mm.), flowers small, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge; pods small ( $19.1 \times 13.1$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 126.0 gm.

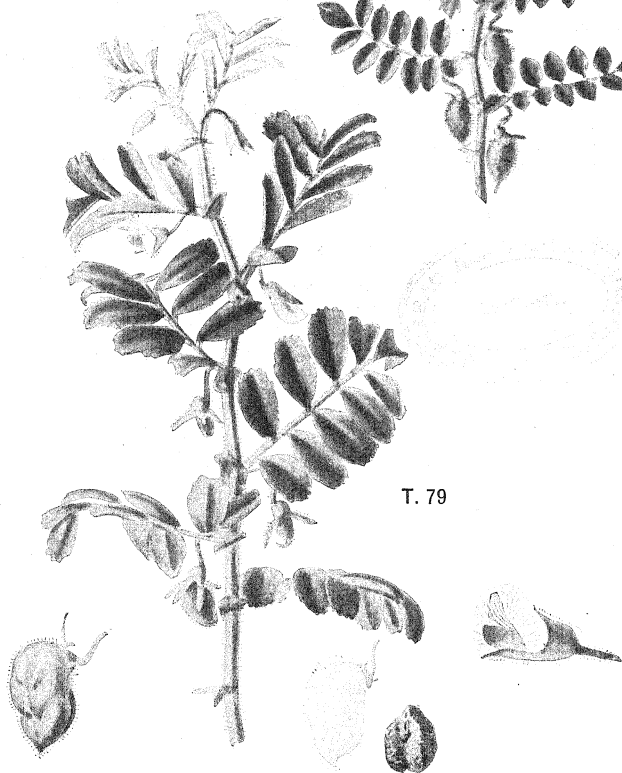
Type 24. Late; habit erect; leaves light green, leaflets medium in size ( $11.3 \times 7.0$  mm.); flowers small, solitary, pink, standard and wings pink with deep bluish tinge, standard caducous, glabrous; pods small ( $18.5 \times 13.1$  mm.); seeds small, very dark brown, irregular, smooth, weight of 1,000 seeds 142.0 gm. (Plates I and II).

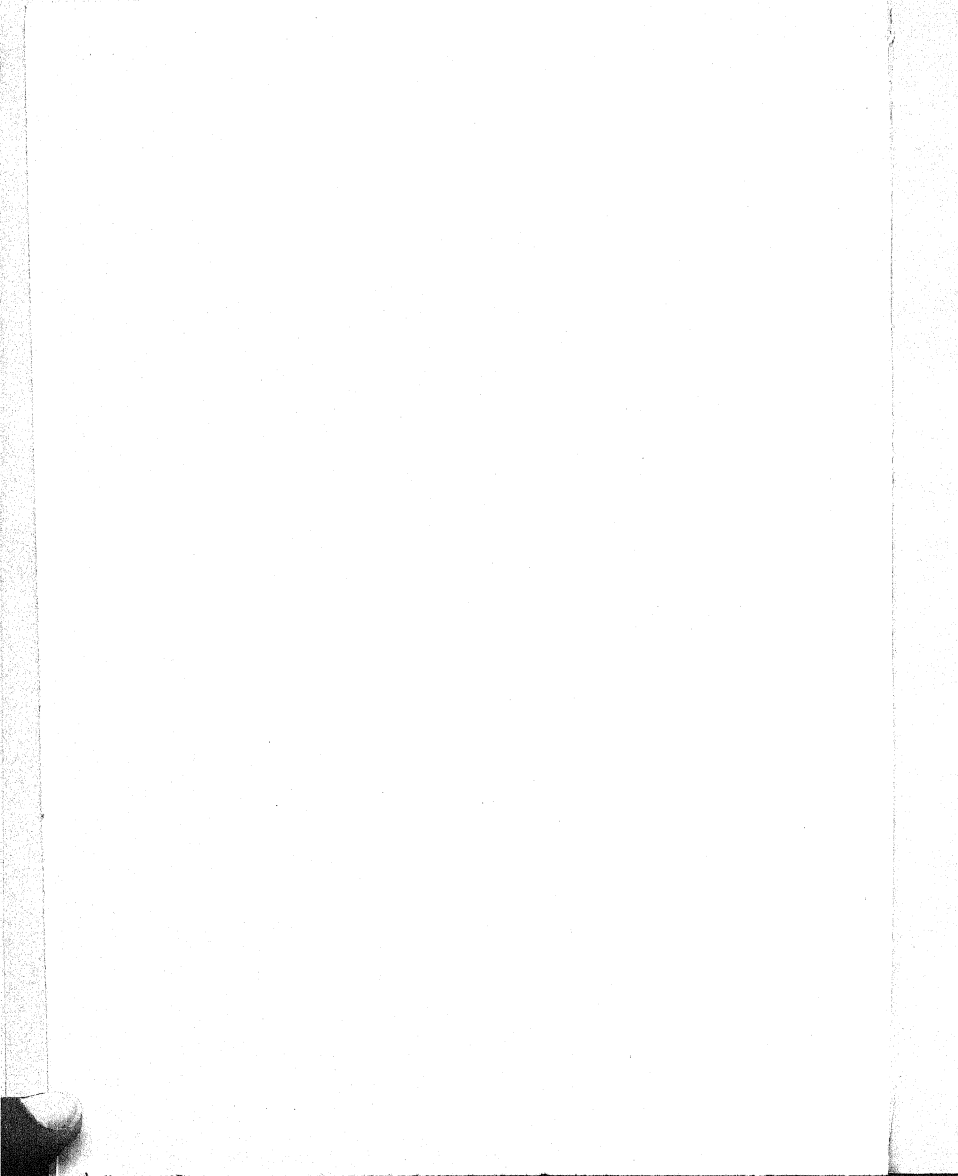
Type 25. Intermediate in maturity; habit erect; leaves dark green, leaflets medium in size ( $11.1 \times 6.5$  mm.); flowers small, solitary, pink, standard and wings reddish, standard caducous, glabrous; pods small ( $19.8 \times 12.7$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, smooth, weight of 1,000 seeds 113.2 gm. (Plate I).

T. 22



T. 79





Type 26. Intermediate in maturity; habit erect; leaves dark green, leaflets large ( $17.1 \times 11.6$  mm.); flowers large, solitary, white; standard caducous, glabrous; pods large ( $25.5 \times 17.1$  mm.); seeds large, white with a reddish yellow tinge, round, puckered, weight of 1,000 seeds 303.0 gm.

Type 27. Intermediate in time of maturity; habit erect, leaves very dark green, leaflets medium in size ( $14.3 \times 9.2$  mm.); flowers medium in size, solitary, white, standard caducous, glabrous; pods large ( $25.2 \times 16.3$  mm.); seeds medium in size, white, round, puckered, weight of 1,000 seeds 252.0 gm.

Type 28. Intermediate in maturity; habit erect; leaves dark green, leaflets medium in size ( $13.3 \times 8.3$  mm.); flowers medium in size, solitary, white, standard caducous, glabrous; pods medium in size ( $22.8 \times 14.5$  mm.); seeds medium in size, white, round, puckered, weight of 1,000 seeds 193.5 gm. (Plate II).

Type 29. Intermediate in maturity; habit erect; leaves light green, leaflets medium in size ( $13.1 \times 8.0$  mm.); flowers medium in size, solitary white, standard caducous, glabrous; pods medium in size ( $24.6 \times 13.7$  mm.); seeds medium in size, orange, round, smooth, weight of 1,000 seeds 214.0 gm. (Plate II).

Type 30. Intermediate in time of maturity; habit erect; leaves dark green, leaflets medium in size ( $13.0 \times 8.0$  mm.); flowers small, solitary, white, standard caducous, glabrous; pods medium in size ( $22.7 \times 15.5$  mm.); seeds small, white with yellowish tinge, round, puckered, weight of 1,000 seeds 168.0 gm.

Type 31. Early; habit erect; leaves green, leaflets medium in size ( $11.6 \times 6.9$  mm.); flowers small, solitary, white, standard caducous, glabrous; pods small ( $19.2 \times 13.2$  mm.); seeds small, white with a yellowish tinge, round, puckered, weight of 1,000 seeds 123.0 gm.

Type 32. Intermediate in time of maturity; spreading; leaves dark green, leaflets medium in size ( $11.7 \times 6.6$  mm.); flowers small, solitary, white, standard caducous, glabrous; pods small ( $18.9 \times 12.9$  mm.); seeds small, white with yellowish tinge, round, puckered, weight of 1,000 seeds 138.5 gm.

Type 33. Intermediate in time of maturity; habit erect; plants taller than Type 34; leaves dark green, leaflets medium in size ( $14.4 \times 9.5$  mm.); flowers small, solitary, white, standard caducous, glabrous; pods medium in size ( $22.1 \times 14.4$  mm.); seeds small, white with yellowish tinge, irregular, slightly granulated, weight of 1,000 seeds 161.0 gm.

Type 34. Intermediate in time of maturity; habit spreading; leaves dark green, leaflets medium in size ( $11.9 \times 7.5$  mm.); flowers small, solitary, white, standard caducous, glabrous; pods medium in size ( $21.3 \times 13.4$  mm.); seeds small, light fawn, irregular, slightly granulated, weight of 1,000 seeds 125.5 gm.

Type 35. Late; slightly spreading; leaves dark green, leaflets large ( $15.5 \times 10.8$  mm.); flowers small, solitary, white, standard caducous, glabrous, pods medium in size ( $20.3 \times 15.9$  mm.); seeds small, orange, round, smooth, weight of 1,000 seeds 170.0 gm.

Type 36. Early; erect; leaves light green, leaflets medium in size ( $15.0 \times 7.6$  mm.); flowers large, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods medium in size ( $21.5 \times 14.8$  mm.); seeds medium in size, yellow pink, irregular, smooth, weight of 1,000 seeds 222.0 gm.

Type 37. Early; erect; leaves green, leaflets medium in size ( $11.4 \times 10.5$  mm.); flowers large, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods medium in size ( $20.8 \times 14.3$  mm.); seeds medium in size, yellowish pink, irregular, smooth; weight of 1,000 seeds 222.0 gm.

Type 38. Early; erect; leaves dark reddish green, leaflets medium in size ( $11.9 \times 8.0$  mm.); flowers large, solitary, pink, standard and wings pale pink with a general bluish tinge; standard caducous, glabrous; pods medium in size ( $22.0 \times 14.6$  mm.); seeds medium in size, yellowish pink, irregular, smooth, weight of 1,000 seeds 220.0 gm.

Type 39. Intermediate in time of maturity, spreading; leaves light green, leaflets medium in size ( $13.0 \times 7.9$  mm.); flowers large, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods medium in size ( $20.4 \times 14.5$  mm.); seeds medium in size, yellowish pink, irregular, smooth, weight of 1,000 seeds 252.0 gm.

Type 40. Intermediate in time of maturity, spreading; leaves dark green, leaflets medium in size ( $12.1 \times 8.2$  mm.); flowers large, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods medium in size ( $22.8 \times 15.3$  mm.); seeds medium in size, yellowish pink, irregular, smooth, weight of 1,000 seeds 242.5 gm. (Plate II).

Type 41. Intermediate in time of maturity; erect; leaves dark green, leaflets medium in size ( $14.9 \times 8.1$  mm.); flowers medium in size, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods small ( $19.7 \times 14.5$  mm.); seeds medium in size, yellowish pink, irregular, smooth, weight of 1,000 seeds 237.5 gm.

Type 42. Early, erect; leaves very dark reddish green, leaflets medium in size ( $12.9 \times 7.3$  mm.); flowers large, solitary, pink; standard and wings reddish with a general bluish tinge, standard caducous, glabrous; pods small ( $19.3 \times 13.9$  mm.); seeds medium in size, yellowish pink, irregular, smooth, weight of 1,000 seeds 210.0 gm. (Plate I).

Type 43. Intermediate in time of maturity, erect; leaves dark green, leaflets medium in size ( $14.0 \times 8.7$  mm.); flowers medium in size, solitary, pink, standard and wing pale pink with a general bluish tinge, standard caducous, glabrous; pods medium in size ( $23.6 \times 14.3$  mm.); seeds medium in size, yellowish pink, irregular, distinctly granulated, weight of 1,000 seeds 180.0 gm. (Plate II).

Type 44. Early, erect; leaves very dark green, leaflets medium in size ( $14.7 \times 8.4$  mm.); flowers medium in size, solitary, pink; standard caducous, glabrous, light pink, wings violet above, pink below with slight bluish tinge, pods small ( $19.9$

$\times 13.4$  mm.); seeds medium in size, dark reddish brown, irregular, rough, weight of 1,000 seeds 187.5 grm.

Type 45. Early, erect; leaves dark green, leaflets medium in size ( $11.6 \times 6.6$  mm.); leaf axil red; flowers medium in size, solitary, pink; standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods small ( $19.9 \times 13.4$  mm.); seeds medium in size, dark reddish brown, irregular, rough, weight of 1,000 seeds 186.5 grm. (Plate II).

Type 46. Late, erect; leaves dark green; leaflets small ( $10.1 \times 5.3$  mm.); flowers small, solitary, pink, standard and wings reddish, standard caducous, glabrous; pods medium in size ( $20.1 \times 13.1$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, smooth, weight of 1,000 seeds 118.5 grm.

Type 47. Early, erect; leaves dark green, leaflets medium in size ( $11.7 \times 5.7$  mm.); flowers small, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with a slight bluish tinge; pods small ( $17.9 \times 12.2$  mm.); seeds small, yellowish brown turning to reddish brown on maturity, irregular, smooth, weight of 1,000 seeds 134.5 grm.

Type 48. Differs from Type 47 only in having occasional red colour in the axil of leaf.

Type 49. Differs from Type 48 in having distinct red colour in the axil of leaf, and darker colour of the foliage, weight of 1,000 seeds 108.0 grm.

Type 50. Intermediate in time of maturity; erect; leaves light green, leaflets small ( $10.8 \times 5.8$  mm.); flowers small, solitary, pink; standard caducous, glabrous, light pink, wings violet above, pink below, with a slight bluish tinge, pods small ( $17.0 \times 12.0$  mm.); seed small, yellowish brown, irregular, smooth, weight of 1,000 seeds 109.5 grm.

Type 51. Intermediate in time of maturity, erect; leaves green, leaflets small ( $9.6 \times 5.9$  mm.); flowers small, solitary, pink; standard caducous, glabrous, light pink, wings violet above, pink below, with a slight bluish tinge; pods small ( $19.3 \times 12.3$  mm.); seeds small, yellowish brown, irregular, smooth, weight of 1,000 seeds 116.0 grm.

Type 52. Intermediate in time of maturity, erect; leaves very dark reddish green; leaflets small ( $8.7 \times 5.5$  mm.); flowers medium in size, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below with a slight bluish tinge; pods small ( $18.4 \times 12.0$  mm.); seeds small, yellowish brown, irregular, smooth, weight of 1,000 seeds 107.0 grm.

Type 53. Early, erect; leaves green, leaflets medium in size ( $11.7 \times 6.4$  mm.); flowers medium in size, solitary, pink; standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods small ( $18.6 \times 12.6$  mm.); seed small, yellowish brown, irregular, smooth, weight of 1,000 seeds 132.0 grm.

Type 54. Early, erect; leaves dark green, leaflets small ( $8.7 \times 5.0$  mm.); flowers small, solitary, pink, standard and wings pale pink with a general bluish tinge,

standard caducous, glabrous; pods small ( $17.0 \times 12.3$  mm.); seeds small, yellowish brown, irregular, smooth, weight of 1,000 seeds 105.2 gm.

Type 55. Differs from Type 54 only in having slight red colour in the leaf axil, weight of 1,000 seeds 129.0 gm.

Type 56. Differs from Type 55 only in having distinct red colour in the leaf axil, weight of 1,000 seeds 137.5 gm.

Type 57. Intermediate in time of maturity, erect; leaves light green, leaflets small ( $10.8 \times 5.4$  mm.); flowers small, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous, pods small ( $17.9 \times 11.7$  mm.); seeds small, yellowish brown, irregular, smooth, weight of 1,000 seeds 118.5 gm.

Type 58. This type differs from Type 57 in having green leaves and also in size of leaflets which is medium ( $12.1 \times 7.1$  mm.); weight of 1,000 seeds 133.0 gm.

Type 59. This type differs from Type 58 in having dark green leaves only, weight of 1,000 seeds 137.5 gm.

Type 60. Late, erect; leaves light green, leaflets small ( $10.5 \times 5.7$  mm.); flowers small, solitary, pink, standard and wings pale pink with a general bluish tinge; standard caducous, glabrous; pods small ( $17.8 \times 11.5$  mm.); seeds small, yellowish brown turning to reddish brown, irregular, smooth, weight of 1,000 seeds 120.5 gm.

Type 61. It differs from Type 60 in having green leaves; weight of 1,000 seeds 108.0 gm.

Type 62. Early, erect; leaves light green, leaflets small ( $9.4 \times 5.3$  mm.); flowers small, solitary, pink, standard and wings reddish; standard caducous, glabrous; pods small ( $17.6 \times 12.9$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, smooth, weight of 1,000 seeds 138.0 gm.

Type 63. Intermediate in time of maturity, habit erect; leaves green, leaflets medium in size ( $11.7 \times 6.5$  mm.); flowers medium in size, solitary, pink; standard and wings reddish, standard caducous, glabrous; pods small ( $18.6 \times 12.9$  mm.); seeds small, yellowish brown, turning to reddish brown when mature, irregular, smooth, weight of 1,000 seeds 131.2 gm.

Type 64. Early, habit erect; leaves dark green, leaflets medium in size ( $11.2 \times 6.6$  mm.); slight red colour in axil; flowers small, solitary, pink; standard and wings reddish with a general blue tinge, standard caducous, glabrous; pods small ( $19.5 \times 13.5$  mm.); seeds small, reddish brown, irregular, smooth, weight of 1,000 seeds 144.7 gm.

Type 65. Early, habit erect, leaves dark green, leaflets small in size ( $9.0 \times 8.0$  mm.); considerable red colour in the axil; flowers small, solitary, pink; standard and wings reddish with general blue tinge; standard caducous, glabrous; pods small ( $19.3 \times 13.0$  mm.); seeds small, yellowish brown, irregular, smooth, weight of 1,000 seeds 158.0 gm.

Type 66. Early; erect; leaves dark green; leaflets small ( $10.7 \times 6.2$  mm.); flowers small, solitary, pink; standard caducous, glabrous, light pink, wings violet above, pink below with a light bluish tinge; pods small ( $17.3 \times 13.2$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, slightly granulated, weight of 1,000 seeds 143.0 gm. (Plate II).

Type 67. Early, erect; leaves very dark green, leaflets medium in size ( $11.4 \times 6.5$  mm.); flowers small, solitary, pink; standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods small ( $18.0 \times 12.6$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, slightly granulated, weight of 1,000 seeds 112.7 gm.

Type 68. Early; habit erect; leaves dark green, leaflets small ( $11.0 \times 7.1$  mm.); flowers small, solitary, pink, standard and wings pale pink with a general bluish tinge, standard caducous, glabrous; pods small ( $19.0 \times 13.0$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, rough, weight of 1,000 seeds 143.0 gm.

Type 69. Early, erect; leaves dark green, leaflets medium in size ( $11.6 \times 7.1$  mm.); slight red colour in the leaf axil; flowers small, solitary, pink; standard and wings pink with deep bluish tinge, standard caducous, glabrous; pods small ( $19.3 \times 13.0$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, rough, weight of 1,000 seeds 159.0 gm.

Type 70. This type differs from Type 69 only in having moderate red colour in the leaf axil; weight of 1,000 seeds 152.5 gm.

Type 71. This type differs from Type 70 in having very darker green leaves and smaller leaflets ( $10.8 \times 6.5$  mm.); weight of 1,000 seeds 138.2 gm.

Type 72. Early; habit erect; leaves very dark green, leaflets small ( $10.7 \times 6.8$  mm.); flowers medium in size, solitary, pink, standard and wings reddish with a general blue tinge; standard caducous, glabrous; pods small ( $18.9 \times 13.2$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, rough; weight of 1,000 seeds 174.0 gm. (Plate II).

Type 73. Intermediate in time of maturity; habit erect; leaves green, leaflets medium in size ( $12.3 \times 5.9$  mm.); flowers medium in size, solitary, pink, standard caducous, glabrous, light pink, wings violet above, pink below, with a slight bluish tinge; pods small ( $17.7 \times 12.5$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 163.0 gm.

Type 74. This type differs from Type 73 only in having red colour in the leaf axil, weight of 1,000 seeds 148.0 gm.

Type 75. This type differs from Type 74 only in having reddish dark green leaves, and much more red on stem and axil; weight of 1,000 seeds 149.2 gm.

Type 76. Early, habit erect; leaves dark green, leaflets medium in size ( $12.1 \times 6.4$  mm.); flowers small, solitary, pink, standard and wings pale pink with a

general bluish tinge, standard caducous, glabrous; pods small ( $18.0 \times 12.4$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 127.7 gm.

Type 77. Early, habit erect; leaves green, leaflets medium in size ( $11.3 \times 6.7$  mm.); flowers medium in size, solitary, pink, standard caducous, glabrous, standard and wings reddish with a general bluish tinge; pods small ( $18.0 \times 12.8$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 141.5 gm.

Type 78. Intermediate in time of maturity; habit erect; leaves dark green, leaflets medium in size ( $12.6 \times 6.6$  mm.); flowers medium in size, solitary, pink, standard and wings reddish with a general blue tinge, standard caducous, glabrous; pods small ( $18.1 \times 12.8$  mm.); seeds small, dark reddish brown, irregular, smooth, weight of 1,000 seeds 160.0 gm.

Type 79 (mutation in Type 22). Very late in time of maturity, habit erect; leaves light green, leaflets very large ( $16.2 \times 9.6$  mm.); red colour in the axil moderate; flowers large, solitary, pink, standard and wings pink with a deep bluish tinge, standard caducous, glabrous; pods very large ( $31.4 \times 22.6$  mm.); seeds large, dark reddish brown, irregular, granulated not well filled up. (Plate III).

Type 80. Intermediate in time of maturity; habit erect; leaves dark green, leaflets medium in size ( $11.1 \times 6.8$  mm.); distinct red colour in the axil and at the base of new branches; flowers medium in size, solitary, pink, standard and wings reddish with a general bluish tinge, standard caducous, glabrous; pods small ( $17.4 \times 13.2$  mm.); seeds small, dark bluish brown, irregular, smooth; weight of 1,000 seeds 135.0 gm.

Type 81. Intermediate in time of maturity; habit erect; leaves dark green, leaflets medium in size ( $13.3 \times 6.5$  mm.); very slight red colour in axil, flowers medium in size, solitary, pink, standard caducous, glabrous, pale lilac; wings pale pink with a pronounced bluish tinge; pods small ( $18.1 \times 12.5$  mm.); seeds small, dark bluish brown, irregular, smooth; weight of 1,000 seeds 132.0 gm. (Plate I).

Type 82. Intermediate in time of maturity; habit erect; leaves green, leaflets medium in size ( $11.6 \times 6.9$  mm.); flowers medium in size, two on a pedicel, pink, standard and wings reddish; standard caducous, glabrous; pods medium in size ( $20.8 \times 13.2$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, slightly granulated; weight of 1,000 seeds 136.0 gm.

Type 83. Intermediate in time of maturity; habit erect; leaves dark green, leaflets medium in size ( $12.2 \times 7.3$  mm.); flowers medium in size, two on a pedicel, pink, standard caducous, glabrous, light pink, wings violet above, pink below with a slight bluish tinge; pods small ( $19.7 \times 13.3$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, slightly granulated; weight of 1,000 seeds 133.7 gm.

Type 84. Intermediate in time of maturity; habit erect; leaves dark green, leaflets medium in size ( $11.3 \times 6.8$  mm.); sometimes red colour in axil and at the

base of branches; flowers medium in size, two on a pedicel, pink, standard and wings reddish, standard caducous, glabrous; pods small ( $18.4 \times 12.3$  mm.); seeds small, yellowish brown turning to reddish brown when mature, irregular, slightly granulated; weight of 1,000 seeds 131.0 gm.



## ERRATA.

Memoirs of the Department of Agriculture in India, Botanical Series, Volume XVII, No. 2, October 1928, pages 22 and 26, foot-notes 7 and 2 respectively.

*For—*

Sahasrabudhe, D. L., and Daji, J. A. Nitrogen recuperation in the Bombay Deccan, Part I. *Dept. Agri. India, Mem. Chem. Series*, Vol. VIII, p. 67, 1925.

*Read—*

Rosen, H. R. Efforts to determine the means by which the cotton wilt fungus, *Fusarium vasinfectum*, induces wilting. *Jour. Agri. Res.*, Vol. 33, pp. 1143-1162, 1926.